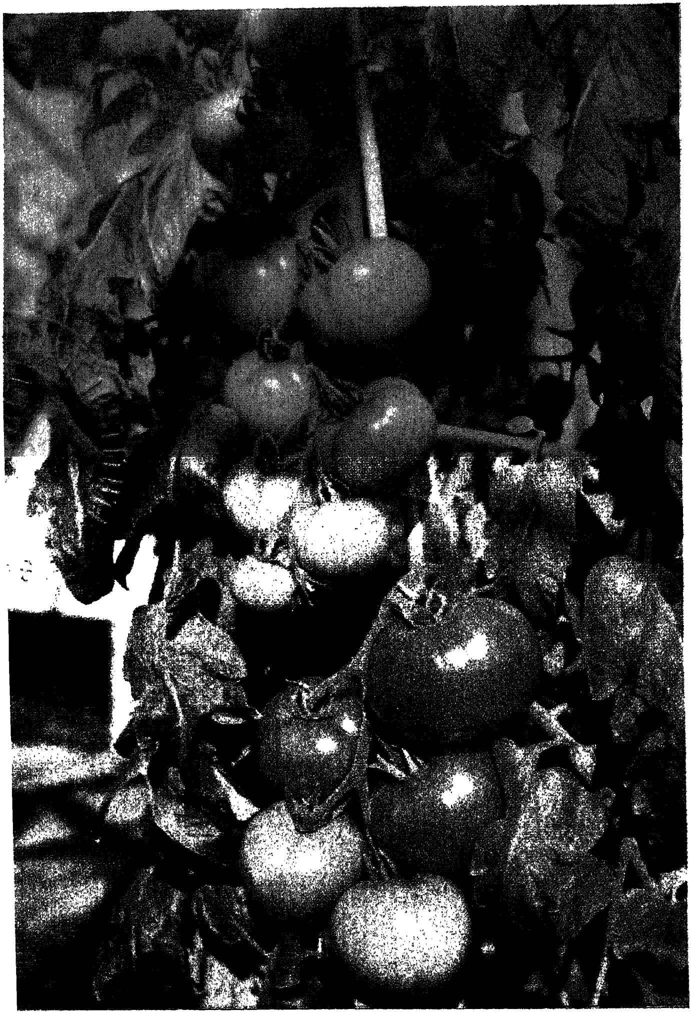

Photo: M. W. Swaney

Close-up of Sand-cultured Vine, showing Quality and Abundance of Both Ripe and Green Tomatoes. Grown by N. J. Agricultural Experiment Station, using the continuous-flow method. (See p. 87.) (Photo by permission of N. J. Agricultural Experiment Station.)

SOILLESS GROWTH OF PLANTS

USE OF NUTRIENT SOLUTIONS, WATER, SAND, CINDER, ETC.

BY

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FOREWORD

ONE of the earliest interests of the senior author was that of experimenting with plants. He began producing cuttings by placing easily rooted stock, such as coleus and geranium slips or cuttings, in moist sand and allowing these to form roots. It seemed as though some good fairy had watched over the vegetation because later the rooted cuttings were potted and sold at the rate of ten cents per plant. At that time the character of the soil used for potting was the important question: a heavy, black earth was considered necessary. Imagine the author's surprise if at that time he had seen similar plants growing vigorously in cinders taken from some nearby stove or furnace!

In the past few years so great a degree of interest has been aroused in so-called soilless growth that a popular discussion of the subject seems in order. The present text was written after numerous laboratory tests and investigations had been carried out. It is hoped that this volume will prove useful to those who desire to grow plants by the methods described herein.

Comments on and photographs of novel set-ups covering methods of soilless growth would be appreciated by the authors. It is desired in subsequent editions to embrace this field in as wide a manner as possible.

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Montclair, N. J.
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INTRODUCTION

IT has been known for a number of years that plants will grow without soil. This means literally growing them in a medium other than soil, sand for example, and supplying them with the necessary food which would ordinarily be furnished by the soil. Since the roots of plants are capable of absorbing and assimilating only food that is in solution, that is, dissolved in water, it matters not whether soil or man furnishes that food.

Like so many other practices, that of soilless growth continued practically unnoticed by the non-technical person until a very few years ago; and within recent months there has been an enormous surge of popular interest in this art of growing plants. The essential feature of the soilless method is the use of so-called "nutrient solutions," which merely consist of chemical plant food dissolved in water. A number of small water-culture gardens employing these nutrient solutions have been in operation during the past year or so, and a considerable number of greenhouse establishments are at present producing both vegetables and flowers by this method of cultivation. Soilless growth is also known as "hydroponics," aquaculture, water-culture, tray agriculture, or tank farming. When carried on in the proper manner, it enables one to obtain plants of considerably larger size than is ordinarily attained in soil. For instance, tomato vines 25 feet in height have been reported grown by soilless methods.

Soilless-growth techniques possess certain definite advantages over soil methods of producing plants. Countless soil diseases, which at present are causing untold trouble even to the professional greenhouse worker, should not occur in soilless-growth operations. In addition, such soil-plant detriments as drouth, for example, do not materially affect solution-nour-

ished plants, since these do not depend on the soil for their sustenance. In addition, soilless-growth establishments can be operated in localities where soil is either absent or else unfit for growing plants.

In this book the authors have presented a concise and non-technical discussion of the chemistry of plant life and a review of the three recognized modifications of *soilless growth,* namely, *water-culture, sand-culture,* and *sub-irrigation* systems. Numerous household experiments have been included, liberally supplemented by photographs, which may serve to enable the reader to carry on soilless growth experiments at home for the purpose of producing vegetables and flowers for the family.

An exceedingly active phase of plant growth at the present time is that dealing with the functions of plant hormones, of which there are quite a number. The authors have included concise resumes of the hormone work together with a discussion of the phenomenal discoveries of recent months on the doubling of chromosomes in plants. These discoveries represent a controlled chemical method of doubling plant chromosomes which is believed to be of utmost importance in the possible development of many new strains of plants.

Another chapter deals entirely with the preparation of nutrient formulas, and a number of widely used formulas are listed. In addition, the reader has been informed of some of the difficulties often encountered in growing plants, both in soil and in soilless-growth systems. Particular emphasis has been placed on those detriments most likely to be associated with the latter.

Accounts are given of a number of large-scale soilless-growth operations being carried on at the present time, together with a discussion of the promise of soilless-growth techniques in plant cultivation of the future.

Finally, the authors have attempted to repudiate some of the widely circulated, but erroneous, claims made for soilless-growth practices. The reader is warned that plants grown without soil need attention just as do those grown in soil.

Although no guarantee is offered that every amateur experimenter will be successful—all new methods are accompanied by occasional failures—explicit directions and methods are given herein which have been employed successfully by various experimenters. Rather than cast soilless-growth in the role of a method of growing plants which is entirely free from error, the authors have attempted to present it in its true light, although definite attention has been called to its proven advantages.

Even though the reader does not plan to grow plants without soil, it is hoped that the information contained in this book will prove interesting and informative. Carrying on soilless-growth experiments should constitute an exceedingly fascinating work for anyone entering it.

CHAPTER ONE

CHEMISTRY OF PLANT LIFE

ONE often marvels at the complexity and intricacies of the mechanism of the human body. How wonderful it is indeed that food and oxygen and water can be consumed and transformed in only a few hours into (a) energy to motivate man's physical being; (b) energy to activate his thought processes; (c) means of furnishing new life for the blood that flows in his veins, new material for the growth of his organs, and even contributions to a reservoir of potential energy, stored-up fat. And daily we are becoming more and more conscious of the importance of vitamins and hormones (complex messengers that govern our bodily processes) and gland secretions in our every-day lives.

But, on the other hand, how many of us who have not studied the physiology of plant life merely accept the existence of the plant kingdom as a matter of fact? To most of us, a seed is planted, or a branch or cutting is inserted in the ground with little consideration of what is going to take place. It either grows or it doesn't grow. Perhaps we blame the seed as being faulty, or perhaps the soil was of the wrong type. But, how many of us realize what makes the seed active or dead, or the soil "rich" or "poor"? Does a rosebush grow for us because we were born under the right star, and do the potatoes in our garden refuse to come up because we planted them at the wrong time of the moon?

No, definitely not. Far different it is from that, and far more complicated, too. The scientist who "knows" plants and plant life, who understands the physiological reactions going on within the cell wall, realizes only too well that the complexity of all plants, from the loveliest of Madame's orchids to the lowliest of the weeds, is certainly at least on a par with

that most temperamental of all mechanisms, the human body.

As in the case of animals, plants, too, have been found to require certain hormones, or accelerators, for proper growth; and their very existence depends on the presence and activity of a substance called protoplasm, the life-giving fluid present in every living cell, whether animal or vegetable. Certain complex chemicals must be present to cause roots to grow. Likewise, the elongation and subdivision of cells (the way in which plants grow) depend on the presence of the necessary hormones or catalysts.

Life Processes of Plants

But first let us review the fundamental processes going on inside a plant. The requisites for plant growth are, namely: (1) the seed or other propagating unit; (2) a food source (soil, etc.); (3) oxygen, carbon dioxide and water; (4) sunshine (or artificial light); and (5) hormones, or "auxins," etc. The essential reaction going on within a plant is the production of formaldehyde which in turn gives carbohydrates and eventually cellulose, which forms the "skeleton" of the plant. This process, generally known as "photochemical synthesis," consists in the reaction of water, taken from the soil, etc., by the roots of the plant, with carbon dioxide (commonly known as dry-ice gas) taken from the atmosphere by the foliage. These substances react inside the leaf to form formaldehyde and oxygen. This reaction is made possible by the action of light (from the exterior) and is catalyzed (directed) by chlorophyll, the green substance (pigment) of all living plants. Chemically, the reaction is represented as follows:

$$\underset{\text{(water)}}{H_2O} + \underset{\text{(carbon dioxide)}}{CO_2} \longrightarrow \underset{\text{(formaldehyde)}}{CH_2O} + \underset{\text{(oxygen)}}{O_2}$$

This constitutes part of the "carbon cycle" relationship existing between plants and animals. That is, the plant absorbs carbon dioxide from the air and liberates oxygen (with few

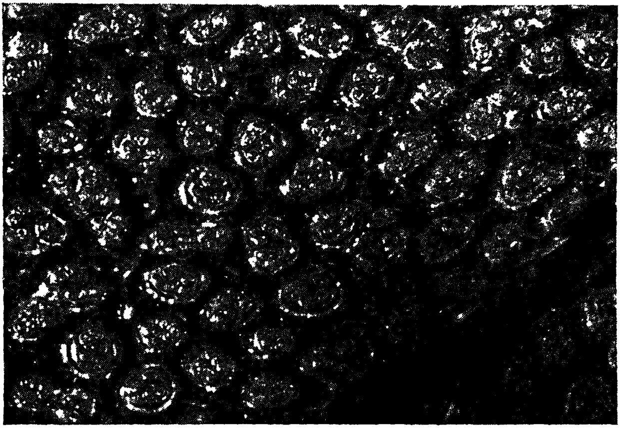
exceptions). Animals, on the other hand, breathe in oxygen and exhale carbon dioxide.

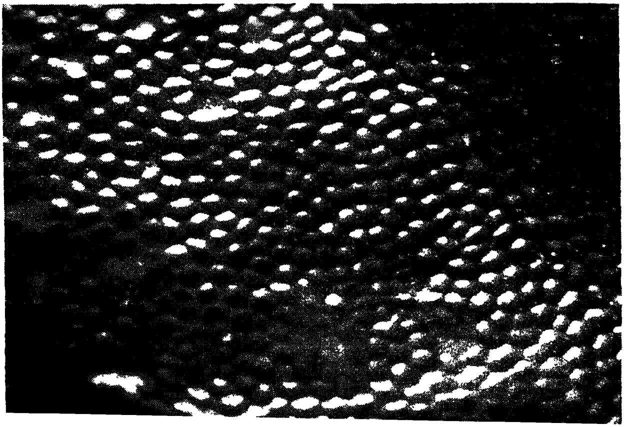
Thus, the formaldehyde (often used as a disinfectant) formed in the above manner becomes the initial building unit; from it are formed sugars and starches, and finally cellulose, which goes to make up plant cell walls and tissue. This is all brought about by the fact that, under the conditions of a leaf interior, formaldehyde is capable of condensing with itself, that is, several molecules of this gas react with one another and form sugars and starches. But to say merely that the plant causes carbon dioxide and water to react is not enough to satisfy the curious observer.

Breathing Mechanism

For example, carbon dioxide, which seems common enough to us, occurs in the atmosphere in a very low concentration, only about three parts in ten thousand, being even scarcer than one of the so-called "rare gases" (argon). Plants, however, extract the necessary carbon dioxide from the air by means of innumerable tiny pores on the under side of the foliage. Too small to be seen with the naked eye or even with some microscopes, these tiny mouths, called *stomata,* breathe air into the leaves, where carbon dioxide is removed and reacted with water in the leaf cells, wherein chlorophyll is contained. The oxygen liberated is ejected as exhaust and fresh air containing carbon dioxide drawn in.

Thus is constituted the first operation in the world's smallest factory, and, needless to say, the most important. If for some reason the cells lose water too fast because of overheating, or are attacked by injurious foreign matter, the stomata automatically close, partly or entirely, and the growing process slows down or ceases altogether. On the proper functioning of these infinitesimal stomata and the microscopic cells within the leaves the entire life of the earth is dependent. For without proper breathing of the stomata the production of the entire food supply for all plants and animals would cease.





Figs. 1 and 2. Photomicrographs of Begonia Leaf. Top photograph, of lower side of leaf, shows clusters containing stomata, the tiny mouths through which the plant breathes. Lower photo shows cellular structure of plants as exhibited by top side of leaf. Both sections enlarged 20 times.

Equally important, though, is a plant's respiration. In this process the plant absorbs oxygen from its surroundings and uses it to oxidize part of its own carbohydrates. This operation furnishes energy for the plant's activities. Thus we find photosynthesis (plant absorbs carbon dioxide and gives off oxygen) and respiration (plant absorbs oxygen and gives off carbon dioxide) going on within a plant at the same time, although very often at different rates. It has been stated that during the life of a plant its carbon dioxide absorption is about equal to its oxygen utilization.

Green Pigment

Little as yet has been said about the all-important chlorophyll, the green substance of plants. This complex chemical acts as the intermediary whereby the carbon dioxide and water molecules enter the plant, come together and react under the influence of the radiation of the sun. So tremendously important is this substance chlorophyll that we venture to present a greatly simplified statement as to its chemistry. As a matter of fact, chlorophyll, which was long thought to be a single substance, is really composed of two components, chlorophyll *a* and chlorophyll *b*. These contain carbon, hydrogen, oxygen, nitrogen and magnesium.* Chlorophyll *a* is blue-black, while chlorophyll *b* is dark green. Together they impart the green color to living plants. More recently it has been found that the chlorophylls are combined, in plants, with a complex protein. The latter is quite unstable and for a long time was decomposed by the procedure generally employed for isolating the chlorophylls. Coagulation of this material might account for the change in color which occurs when a green leaf is plunged into hot water. The two chlorophylls are further associated, in plants, with yellow and sometimes also with reddish-brown pigments. The amount of chlorophyll increases as the plant matures.

* The chemical formulas are $C_{55}H_{72}O_5N_4Mg$ and $C_{55}H_{70}O_6N_4Mg$, respectively.

Sap Rise

But now let us travel from the leaves inward to the stem, or stalk, of the plant and see just what goes on there. On careful observation we find countless cells giving body to the plant and never-ending streams of sap flowing through the stalk. These streams, which can be considered as analogous to blood streams in the human body, constitute a ceaseless flow of food and life substances to cells which are existent and to the new cells that are continually forming. Just what causes sap to rise and the manner in which this is accomplished has been the topic of considerable discussion. Certainly there must be some very active force which would push sap to the tops of our tallest trees. This force is scientifically known as osmotic pressure, and it is vital to plant life. Previously it was believed that the osmotic pressures developed inside plants were quite moderate and did not entirely account for sap rise. Recently, though, a young experimenter at the Rockefeller Institute for Medical Research worked with the tiny tomato root and found that it developed pressures sufficient to force sap 200 feet high. It is evident that tomato vines never grow to this height, but this at least offers an opportunity for conjectural prophecies of the future.

Recently published work indicates that certain plants, for instance the onion, can be disjointed and connected by short sections of glass tubing and still continue to live.

Cells? What are they? Perhaps it would be well to consider them as building units, just as small bricks go to make a tall building, or as small compartments go to form the comb of the honey bee. They differ in size among plants, of course, but all are formed in more or less the same way, and all serve the same purpose. Essentially they are small compartments consisting of thin, more or less permeable walls and contain protoplasmic fluid, which gives life to the plant, together with sugars, starches, proteins, etc. A plant grows by two cell functions, namely, by cell stretching or elongation, and by cell division.

In the tips of plants, either the sprout-tips or root-tips, embryonic or immature cells are ever present. These are always of two types, either *stretching* or *dividing cells.* Some of these cells continually subdivide themselves into new cells, while the remainder do not divide, but continue to grow or elongate themselves instead. Thus a dividing cell may give rise to a dividing cell and a stretching cell. The latter thereafter expands, while the dividing cell in turn gives rise to new cells. The tip of every plant contains a "growth substance" or "hormone" which is transported to underlying cells and causes them to stretch or "grow." Thus, if the tip is cut off, the plant ceases to grow, unless, of course, these hormones (sometimes called "plant auxins") are added artificially.

What causes the auxin to move from the growing tip to cells below has not been definitely agreed. The theory of diffusion has been discounted because the auxin moves too rapidly (about 1 centimeter per hour). It has been suggested that the transportation of this hormone might be due to electrical forces, but this has not been definitely proven to be true, although the application of electrical currents to growing plants has resulted in greatly increased growth.

Functions of Roots

Having considered some of the changes occurring in the leaves and stalks of plants, let us now pass to the part of the plant below the ground, namely, to the roots. Not being able to pierce the earth with their eyes, most persons have little or no conception of the massiveness of the roots belonging sometimes to even small plants. Sizable trees may have roots extending a surprising number of feet in all directions. Potted plants naturally do not possess roots extending beyond the limits of the pots, but when roots have unlimited space in which to grow, they do indeed become extensive. This must of necessity be true because upon the roots depends the life of the plant. True, a plant must receive air and light through its upper portions, but without the food furnished by the roots

Fig. 3. Photograph showing Massiveness of Root System of the Sweet Potato (actual size). This represents only a portion of the root system of a single plant grown by soilless-growth method.

light and air would be of little value. A small vine, *e.g.*, a potato vine a few feet in length, may have a combined root length of more than a hundred feet. Roots of biennial white clover grown in soil have been known to extend twenty feet from the base of the plant. Although each individual root is small, the combined surface area of contact of roots with soil is indeed enormous. The function of the roots is two-fold, namely, (1) to lend support to the plant and (2) to furnish food and water for growth.

It is the duty of the roots to extract water from the soil so that in times of drought the plant can continue to live. During rainy periods water is absorbed by the soil and held in reserve. In dry weather the roots must "take away" this moisture for

their own use. Secondly, the roots must furnish the necessary chemical elements for the life of the plant.

Fig. 4. Photomicrograph of Sweet Potato Root of Fig. 3 (enlarged 20 times). Note roughened appearance of root surfaces.

It was stated earlier that carbon dioxide and water react in the leaves and stalks of plants to furnish sugars and starches, and that hormones in the tips of plants cause the cells to grow. This is quite correct, but without the presence of certain chemical elements to catalyze (make possible) these life processes, the plant could not exist.

Function of Soil

The soil, or, at least, a good soil, contains all the elements necessary for plant life. Some poorer soils must be enriched with these elements. Most of the necessary elements are present in the soil in a very insoluble condition, however; otherwise the soil elements would have washed away long ago. When rain water percolates through soil, it tends slowly to dissolve elements out of it. These it takes to the roots which extract the elements needed. In addition water allows micro-organisms to grow in the soil. These bacteria in turn tend to decompose soil particles chemically and furnish elements to the roots, and in addition supply carbon dioxide to the plant. It has been shown that in the soil, micro-organisms tend to segregate in the immediate vicinity of the roots and are more abundant there than at short distances from them. Perhaps this is one of nature's methods of coöperative preservation. In this connection might be mentioned the role of soil bacteria in fixation of nitrogen. This means that these bacteria convert the nitrogen of the air into a chemical form capable of nourishing plants.

The primary roots which branch out abundantly from the base of a plant have, in turn, secondary roots branching out from them. Probably these secondary roots, or "root hairs," are largely responsible for collecting the plant's food. It is believed that roots contain innumerable small doors through which food is drawn in. Growing plants in culture media (discussed in later chapters) allows greater opportunity for studying root phenomena than do plants grown in soil.

In poor soils the root systems are more extensive than in

Fig. 5. Photomicrograph of Tomato Seed Germinating between Moist Paper (enlarged 20 times). Note tiny root hairs on tip of large roots emerging from lower parts of seed. It is through these hairs that food is sucked into the plant.

rich soils. If the fight for food is more strenuous, then the roots are developed accordingly. When plants are grown in nutrient solutions, their root systems are smaller yet, since a sufficiency of food is always available, and the roots do not have to go out and "search" for it. Still another function of the soil, and one which should not be overlooked, is that of providing an efficient means of aerating the roots. Roots must breathe just as the leaves do, and the deleterious effects of poor aeration of roots have been pointed out many times. The soil is naturally quite porous. Due to temperature changes between day and night, when air expands and contracts, the ground literally breathes air in and out. In soil farming the purpose of plowing is to break the soil's upper crust and allow better circulation of air among the roots to take place.

If the functions of the soil could be carried on artificially, then it seems possible that plants could be made to grow without soil. That is, if an artificial means of support is provided, food and water supplied in specially prepared solutions, and the roots given access to air, then the soil might be no longer necessary. This is just what can actually be done and what is described thoroughly later in this book.

Previous mention has been made of the fact that all plants need certain chemical elements in order to grow, but nothing has been said of the specific functions of these elements. In case a deficiency of some one element exists, the plant will grow in spite of it, but growth will not be normal. Perhaps it will be stunted and the leaves malformed, or maybe the leaves will be spotted or will even dry up and fall off. Or perhaps the flower will not blossom properly, or a tomato vine will not bear well. Although plants do not require very many of the ninety-two known elements, the ones that are required must absolutely be available or the plant is sure to suffer.

Role of Elements

The elements necessary for plant life may be divided into two

classes, namely, the *"fertilizing"* elements and the *"trace"* elements. Of the former, nitrogen, phosphorus and potassium are the most important, with calcium, magnesium and sulphur running close seconds. These elements must be furnished in relatively abundant proportions (about 1 part each in 5000 parts of solution). Of the trace elements, iron, manganese, boron, and zinc, and perhaps copper are the most important. Quite a number of additional trace elements have been advocated by various experimenters, but the importance of these elements has been open to question. The "trace" elements, as the name implies, must be present in very low concentrations or considerable injury may result to the plant. Boron, for example, must be present as ½ part of boron per one million parts of soil solution. If this concentration is doubled (1:1,000,000), then boron becomes definitely detrimental.

Nitrogen, which is so very important in plant life, is a building-block which is necessary for the production of proteins. Proteins, in turn, are the materials of which protoplasm, the life-substance, is composed. Nitrogen, when supplied to the soil in fertilizers, is generally added in the form of nitrates, a large source of which is the Chilean deposits. Nitrogen usually makes for good foliage, and the healthy appearance of a plant is largely due to abundant supply of this element. In addition nitrogen retards the ripening process. On the other hand, when the supply of nitrogen is cut off, the foliage is likely to become yellowish and to assume a starved appearance.

Of course, the very atmosphere we breathe is approximately 80 per cent nitrogen. It so happens, however, that, when in this "native" or "elemental" form, nitrogen cannot be assimilated by plants and must first be "fixed" or converted into compound form. Nature has done this very thing by laying down extensive nitrate deposits in Chile. Man has done it by passing air through electric arcs (causing reaction of nitrogen with oxygen) and particularly by reacting nitrogen with hydrogen to form ammonia. Although nitrogen in the form of ammonia can be utilized by plants, especially in the later

stages of growth, it has been found that nitrogen is far more effective in the form of nitrates.

During the early and even middle life of a plant its nitrogenous matter is found principally in the foliage and stalk portions. When maturity has been reached, however, these proteins are transported to the seeds, or other similar reservoirs, and become concentrated there. Plants which are grown solely for foliage, such as lettuce, cabbage, etc. naturally are greatly benefited by plenty of available nitrogen. Thus the expression that "nitrogen makes foliage" is found quite true.

Phosphorus, too, is extremely essential for plant life, but its scarcity is not as visibly noticeable as that of nitrogen. Phosphorus stimulates healthy root growth and hastens the ripening process. The element itself is an important constituent of some proteins, and a deficiency of phosphorus slows down growth by retarding cell division.

The plant takes phosphorus from the soil as phosphates, and an abundant supply of available phosphorus stimulates seed production. During the growth of the plant phosphorus is found in the leaves and upper portions. While in this region, however, phosphorus atoms do not remain fixed in any one portion of the plant but are continually moving about. It has been observed that these atoms are ceaselessly changing from leaf to leaf during the entire growth of the plant. Near seeding time, however, large amounts of phosphorus migrate to the seeds wherein it becomes concentrated and remains. Quite commonly it is aptly stated that "phosphates make seeds."

Potassium is so vital for the photosynthesis of starch and its translocation that the whole process ceases to function if an insufficiency exists. The expression that "potash makes sugars and starch" is particularly true. Naturally, then, crops which have a large starch content (potatoes, etc.) suffer most when the supply of potassium becomes deficient. Although potassium is not a constituent of any of the carbohydrates, it is in some unknown way connected with the manufacture of them in plant cells.

Potash-hungry plants have in addition been found more susceptible to disease than well nourished ones. For example, plant cancer due to *Bacterium tumefaciens* is favored by potassium deficiency.

Next in the series of fertilizing elements is *calcium*. It appears to stimulate root growth and is thought to add strength to cell walls. It remains in the leaves and stalks as the plant matures, although its precise role is not definitely known. Although certain plants cannot tolerate large quantities of calcium, a deficiency of it results in stunted growth (see Fig. 47, extreme left).

Magnesium is thought to be important in plant life in that it seems to aid in the transportation of phosphorus from the older to the younger portions of a plant. In addition, magnesium takes part in the formation of the chlorophyll molecule, which was discussed earlier. It follows, then, that magnesium-hungry plants are apt to lack rich color.

Magnesium is also believed to take an active part in the formation of fats. This follows from the fact that seeds which store up fats rather than starch appear to be richer in magnesium. Like nitrogen and phosphorus, it eventually finds its way to the seeds where it is stored up.

The "storing-up" phenomenon which has been observed in the cases of some of the foregoing fertilizing elements, namely, nitrogen, magnesium and phosphorus, is no doubt nature's way of insuring propagation. In other words, when seeds are planted and first sprout, these stored-up elements serve as food for the seedlings to exist on until they are able to grow sufficient roots to gather up their own food from their surroundings.

Sulphur is likewise an important plant food, and the success of many fertilizers is thought to be due largely to its presence. It occurs in plants associated with phosphorus. Sulphur is believed to promote the growth of bacteria associated with plant life. The effect of bacteria on the latter has been previously mentioned.

Although *silicon* is found in most plants, its role as a definite plant food has not been definitely settled. Some believe it to impart stiffness to cell walls, although experimental data needed to prove this are lacking.

Of the "trace elements," iron, manganese, boron, copper and zinc, which are required in very minute amounts, the first is quite essential for healthy growth. *Iron,* although not a constituent of the chlorophyll molecule, is, nevertheless, necessary for its production. In the absence of iron, no chlorophyll forms, and therefore radiant energy of the sun cannot be harnessed.

Manganese and *boron,* and, in some cases, *zinc,* have been shown to be of importance in plant growth. So important are these elements that their presence in a concentration as low as 1 part in 2 million of food solution may produce a doubled or tripled growth of plants. Their effect is so pronounced, considering their presence in mere traces, that their precise action is not clearly known. It has been observed, however, that boron tends to accumulate in the pistils of apple blossoms, for instance, and is therefore believed to play an important part in the fertilization (sexual) process. It has been shown also that boron in small amounts doubles the yield of beans and that in a complete absence of boron no seeds at all are developed.

In addition boron increases root growth of flax and also speeds up absorption of potassium. Some believe that boron fulfills the duties of true hormones and should be designated as an inorganic plant hormone. It has been scientifically proved that at least a trace of boron must be present before germination of the tropical white water lily can occur.

Although the importance of manganese has been realized for quite some time, recently a scientist found that neither common duckweed nor unicellular green algae (a living fungus often seen clinging to damp flower-pots) would grow at all in culture solutions free of manganese. Healthy growth occurred, however, when manganese was added in a concentration

Fig. 6. Effect of Boron and Manganese Deficiencies. Lettuce on left grown without either of these elements. That on right received both ($\frac{1}{2}$ part of each per million parts of solution). Center plant suffered slightly because of manganese deficiency, as indicated by mottling of leaves. (Courtesy J. W. Shive, N. J. Agricultural Experiment Station.)

of 1 part in 5,000,000 to 10,000,000 parts of water. In addition to manganese, traces of copper and zinc also cause marked increase in plant growth. Copper is believed, like iron, to take an active part in the production of chlorophyll in plants, just as the former element is thought to be essential for the manufacture of haemoglobin in the human body. Furthermore, radium and uranium increase the growth of plants, although their cost prohibits their general use.

So far, this discussion of plant life has been more or less restricted to the interiors of plants and to the soil. Let us now study the effects of some of the external factors on plant life. First let us consider the *effect of light*. As is well known, sunlight is a white light, that is, it consists of a number of colors from infra-red through red, yellow, green, blue and violet to ultraviolet. Of these lights the red has been found more effective than any other component of the visible spectrum, being about twice as efficient as blue light. However,

infra-red light is quite detrimental to most plants, the stomata being eventually closed by too much of this light. It is a common erroneous belief that ultraviolet light is the beneficial factor in all life, particularly plant life. It has been shown, however, that plants can grow very well without ultraviolet, and, in fact, some even grow taller when all ultraviolet is entirely removed. Of course, plants need not have any daylight at all in order to live. They can be grown in the house under ordinary electric lights, if desired. Mazda bulbs are satisfactory, although there is some tendency to overheat the plants if the lights are brought too close. Much greener leaf tissue is produced under sodium vapor or capillary mercury lamps, but their accessibility is limited.

Rest Period in Plants

However, precisely as is the case with animals, plants, too, require a certain amount of sleep, or rest. It so happens that the length of the average day (daylight interval) is not far from the proper length of time that a plant should be illuminated during each 24-hour period. For instance, if a plant receives illumination for 24 hours each day, it is likely to show practically no growth and to have the appearance of being "burned up." When given light for somewhat shorter periods, the plant will grow but will not bear fruit. When the time of illumination approaches that of summer daylight, its growth is most nearly normal.

Although the air contains a small amount of carbon dioxide which is necessary for plant life, experiments show that when plants are subjected to an atmosphere which has been enriched with this gas, they grow considerably larger. The gas hydrogen cyanide, commonly known as prussic acid and used during the World War, is extremely poisonous to animals, but in low concentrations it stimulates growth in a number of trees and shrubs. Corn grown in a soil through which a stream of air is slowly drawn exhibits increased growth over that of corn grown under normal conditions.

So far, much has been said about those materials which are beneficial to plant growth. It might be well also to make mention of some of the difficulties often encountered with the growing of plants. No doubt the most serious of these are insects and virus disease (see Chapter Seven). Naturally, also, lean soils or too alkaline or acid soils would fall into this category, and the farmer is possibly more concerned with these pitfalls. Around industrial centers vegetation often suffers injury because of toxic fumes, although at the present time certain restrictions make it necessary for factories to dispose of toxic gases in other ways than putting them into the air.

Still another factor in growing plants, both in the home and out-of-doors, which in some cases may become very serious, is that of dust. In the home all plants should be sprayed occasionally to remove this dust. Out-of-doors an occasional rain accomplishes this purpose. When dust particles fall on the leaves there is a tendency for the stomata to become clogged and for breathing to be cut off. Obviously the plant must suffer accordingly. It has been found that plant yields may be decreased as much as 100 per cent by allowing dusts to fall upon them.

On certain occasions possibly many have heard the statement that "You can't grow flowers if you use gas." No doubt many have brushed this aside as a mere traditional superstition. Nevertheless, in many cases this may be quite true. Plants are infinitely more sensitive to toxic gases than are animals. For example, the tomato plant is 200 times as sensitive in detecting illuminating gas as is the human nose, a characteristic droop (resembling collapse) occurring. Canaries are used in detecting gas leaks in coal mines. Plants would be much more sensitive for this purpose, but probably so very sensitive that no mine would be found non-toxic. Recent experiments at the Boyce Thompson Institute for Plant Research (Yonkers, N. Y.) revealed that the "bad actor" in illuminating gas is ethylene, a hydrocarbon gas of the formula C_2H_4, and which is widely used in ripening fruit (after harvesting). It was found that

in order to produce approximately the same degree of epinastic response (drooping of branches) the tomato required only 1 part ethylene in 10 million parts of air; the potato 1 part ethylene in 40 million of air; and the African marigold 1 part in 60 million of air.

Therefore, if you have flowers in your home in the winter time, when ventilation is at a minimum, they should be kept as far distant as possible from gas stoves. Usually some unburned gas escapes before a flame is completely lighted. Just remember that the plant is far more sensitive than the nose.

Another gas which is present in illuminating gas is deadly carbon monoxide. This, too, is very poisonous to plants. When animals breathe this gas, it enters the blood stream and reacts with the haemoglobin (the red coloring matter of blood) and causes death. So it is with plants also. There it reacts with the chlorophylls and forms a chemical union, analogous to the haemoglobin complex, thus poisoning the plant.

Still another difficulty which must be considered but which is encountered less frequently is that of growing several plants in the same pot. Certain plants give off excretions through their roots that are definitely injurious to other plants. This may even be encountered when one plant "follows up" another plant. It can usually be obviated, however, by washing the soil with water prior to the second planting. Furthermore, it is not uncommon that certain new flower pots, especially if not properly baked, may contain soluble matter which works its way into the soil and injures the plant.

As a point of interest it might be added that if trouble is encountered with leaf lice, a method reported to be effective for their removal consists of dipping the leaves in a 5 per cent solution of ethyl alcohol in water. This is said to cause no injury to the foliage.

CHAPTER TWO

GROWING IN MINERAL AGGREGATES

IN the preceding chapter were discussed the essential mechanism of plant life and the factors vitally important to flourishing plants. The extremely important role of the soil was clearly emphasized. Also it was noted how the earth so efficiently furnishes water for the plant's very existence, and how it gives up its chemical elements so that the plant may grow. Truly, the soil cannot be praised too highly, because without its relationship to plant life, needless to say, this earth would be barren of animal life today.

SAND-CULTURE METHOD

For the sake of experiment, suppose we should remove a growing plant, for instance, a small tomato vine, from the soil and wash away the clinging particles of earth from its roots. What happens then? Why, the plant soon wilts and dies, of course. Suppose, instead, we should place it in pure sand (merely to give it support) and then pour water around its roots. What then? In that case the vine would continue to live for a few days, perhaps, since two of the functions of the soil would have been fulfilled, namely, the plant would have received support and water. But, as pointed out previously, in order to live and thrive a plant must have more than this. It must have food (chemical elements) on which to live. Therefore, in our second experiment the plant would soon meet a fate similar to that of the plant in the first experiment.

Let us go further with our experimentation and not only place the tomato vine in a mixture of sand and water but also add to this water the fertilizing elements which would normally have been supplied by the soil. First we introduce nitrogen, phosphorus, and potassium, in their chemical combina-

tions, of course, and follow these with additional chemicals containing calcium, magnesium and sulphur. Naturally, we make sure to put in such chemicals as will remain dissolved in the water, or they will otherwise do the plant little good, and further we add sufficient quantities of the chemicals so that the composition of the soil solution is approximated. Then we finally add traces of iron, manganese, boron and zinc. Right before our eyes we see taking place what might be considered by some as the result of waving a magician's wand. We find that the plant continues to grow, possibly even larger than it would have in soil, and that it bears abundant fruit as well. Of course, this does not take place within a few hours or even a few days, but it does take place, *and without soil.* From time to time we add more chemical elements, as the plant uses up those present, and also fresh water occasionally to replace that taken in by the plant's roots. Thus is revealed, very briefly, the principle of soilless growth, or soilless farming, about which this book is written.

Naturally, we are not restricted to the simple method just described. We do not need to grow plants for awhile in soil and later transfer them to sand and nutrient solution. Decidedly not. For example, we can start with tomato seeds and sow them in wet sand, or place them between moistened blotters, or by any of several other convenient methods obtain tomato seedlings within a few days. When large enough these seedlings can be transferred to larger containers carrying sand in which they have access to nutrient solution during their period of growth.

In this way presumably any plant can be grown that will grow in soil and very often it will grow considerably larger than is possible in soil. In the sand-culture system plants always have access to an abundance of available food and water, and, in addition, good aeration of the roots is made possible. As chemical food is used up by the plant over a period of a week or so (depending on the amount of solution present), certain changes go on in the nutrient solution which necessitate its

renewal. For example, roots continually excrete certain substances, and the acidity of the solution gradually changes. Thus, for best results occasional emptying of the tanks followed by the addition of fresh nutrient solution is recommended.

Now, this sand system of growing plants, using the continuous flow method of supplying nutrients which was developed at the New Jersey State Agricultural Experiment Station, may be adapted not only to household growing of plants (both vegetables and flowers respond excellently), but also to large-scale production, the size of the latter installation depending on the amount of capital invested. Needless to say it is not implied that any one method of feeding or watering sand-grown plants is the best. Several modifications have been developed, and the individual experimenter can adopt the one best suited to his particular needs.

The method preferred by some consists of having the nutrient solution stored in a reservoir, from which it drips over the surface of the sand and flows out of the bottom of the sand pot by gravity. It is collected in a container below and returned to the reservoir. In this way the solution which drips has good access to the air and furnishes a very effective means of aerating the roots. Thus, a given amount of solution can be used over and over again until most of its food has been used up by the plant. A set-up of this sort requires as little attention as ordinary soil-grown plants, and sometimes even less. Sand-grown plants possess the further advantage that, should the nutrient solution in the reservoir run out while the attendants are not present, the sand would retain enough food and moisture to prevent any damage to the plant for quite a number of hours.

A simple sand pot arrangement for home use is shown in Fig. 7. Here a fruit jar acts as reservoir. Nutrient solution is delivered by means of a capillary (small internal bore) glass siphon, one end of which is hooked under the rim of the jar, while the other end is suspended over the sand. A small lamp wick or twisted cloth has been suggested as a substitute for

Fig. 7. Continuous Flow Set-up of Tomato Plant Growing in Sand, Nutrient Solution Dripping from Glass Jar which Acts as Reservoir. Small watch-glass or smooth-rimmed saucer should be inverted and placed over drain hole of pot to prevent sand from escaping. (Courtesy J. W. Shive and W. R. Robbins, N. J. Agricultural Experiment Station).

the capillary glass siphon. The rate of dripping is governed simply by adjusting the height of the tip of the siphon in relation to the solution level in the saucer. The size of reservoir can be selected according to the size of the plant or plants. For one or two average-size household plants, a daily flow of one to two quarts of fertilizing solution through the sand should prove sufficient. The larger the plants, the faster the solution should be passed through. It is safe to recommend that changing solutions once each week is sufficient for small to medium-sized plants. No harm, however, results from more frequent renewal of solutions.

The same general principle can be applied to large-scale operations of the sand-culture system. When large trays of sand are used, the solution of plant food is allowed to drip in from numerous inlet tubes spaced evenly over the sand. If the installation is sufficiently large, it is desirable to insert a centrifugal pump between drain pit and reservoir and at intervals transport nutrients back to the reservoir. In this way a continuous recycling of fertilizing solution takes place. (See also Chapters Four and Five.)

Type of Sand, etc.

A word should be said about the type of sand employed. It is wise to use a good grade of quartz sand which has previously been washed thoroughly. It should carry a low alkali content (limestone or dolomite, etc.), otherwise the nutrient solutions will be affected. An added precaution consists of heating it in an oven at about 200° Fahrenheit, or higher, for an hour, or stirring it in boiling water for 15-20 minutes. This insures the removal of any bacteria that might cause damage to the plants.

Care should be exercised in selecting the particle size of sand to be used. If it is too coarse, then too little moisture and food will be retained by it. On the other hand, if the sand is too fine, it will be likely to pack so closely about the roots that insufficient air will reach them to afford good aeration, and the plant will suffer with an ailment commonly referred to

as "wet feet." It has been found that ordinary white "bird sand," or any quartz sand low in calcium carbonate (limestone), which consists of grains the majority of which are about 1/20 inch, or slightly less, in diameter, works very well for the purpose. A sand of this consistency allows good aeration of roots and at the same time retains sufficient moisture for rapid growth.

Germination in Sand

Although seeds may be sprouted in the pots or trays in which they are eventually to be grown, it is usually more economical to do this in a separate and smaller container. A method of producing seedlings which has been tested and found satisfactory consists of sowing seed in sand which is contained in a box or pot equipped for drainage. The sand, which is thoroughly wetted with water, should be three to four inches deep, and the seed should be about one-half inch under the surface. These can be pushed into the sand, or, if preferred, can be strewn over its surface and an additional one-half-inch layer of sand placed on top of them. Next, a solution prepared by adding one part of regular fertilizing solution (Chapter Eight) to three parts of water is poured freely over the sand and allowed to drain. A glass, or other transparent cover, is placed over the container to minimize evaporation and the box is then allowed to stand until sprouting occurs. The box should not be placed in hot sunlight as this will be likely to cause overheating. Occasionally a little water or diluted nutrient solution can be added so as to prevent the seedlings from drying up. Unduly warm places should be avoided because seed sprouted in such surroundings may give rise to seedlings which lack strength and are easily burned when brought into the sun. In the winter time a greenhouse or a room at about 60-70° F. is satisfactory for sprouting. When sprouting seed during the hot summer months, an outdoor spot partially shaded serves very well during the early stages of sprouting.

After a few days the seedlings will pop through the sand

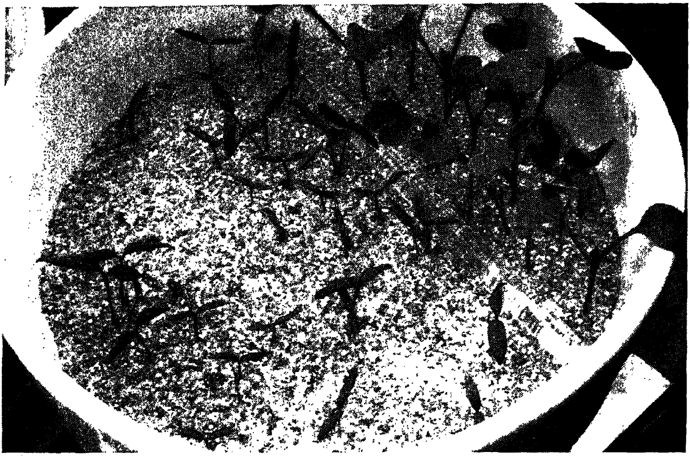


Fig. 8. Tomato Seedlings (left) and Radish Seedlings (right). Produced in Sand Fed by Nutrient Solution. (One-third actual size).

and unfold their tiny leaflets. At this stage they may be brought into the sunlight and the period of exposure may be increased daily until they are able to withstand an entire day's light. However, in no case should the seedlings' container be placed in direct sunlight as long as it is completely covered by glass. This causes overheating under the glass (cooling by evaporation of water cannot take place), and the sprouts may be "cooked" sufficiently to be rendered inactive. Therefore, when the seedling container is brought into bright sunlight, its cover should be at least partly removed. The diluted nutrient solution is added, as needed, to keep the sand moist. An occasional spraying with water alone will wash away accumulated salts which in time may cause injury due to "over-feeding."

When the seedlings have reached a height of several inches, they are ready to be transplanted to larger containers. This may be accomplished with substantially no damage to the seedlings

Fig. 9. Corner of Authors' Greenhouse showing Experimental Sand Pots in Tandem Arrangement. Continuous constant-level siphons deliver the solutions from upper to lower pots.

if reasonable care is exercised. The sand about the seedlings is first flooded with water so as to "loosen up" the roots. Then, by means of a spatula or spoon a single sprout is lifted out. This is next gently placed in a pre-formed hole made in the sand in which it is to grow, and the sand pushed in around it, by means of either the spatula or a small stream of water.

Dripping of the nutrient solution from the reservoir is next begun, and if the vessel contains more than one small plant,

this influx should be allowed to fall midway between them. The plant or plants are now given full-strength nutrient solution, on which they are retained during the entire remainder of their growth. It is not implied that seeds cannot be germinated directly in sand fed by full-strength nutrient solution (continuous flow). On the contrary, this has proven satisfactory for a number of species.

The authors have successfully grown plants in sand pots arranged in tandem order, using a step-like platform (Fig. 9). Three, or even more, pots may be placed one above the other and the efflux from one pot used as influx for the pot below, etc. In this way less attention is required for a large number of pots, although the life of the nutrient solution becomes shorter, since more plants are being fed by it.

In sand cultures plants often grow to enormous sizes and bear fruit abundantly. The porosity of the sand allows relative freedom for growing roots, and the root systems may become extensive indeed. Thus, when a nutrient solution passes through such a sand pot, contact is made with an enormous area of root surface. In view of the fact that plants consume water much faster than they do the fertilizing chemicals, it becomes necessary at intervals to add fresh water to the nutrient mixture in order to overcome this loss. In addition, it is well to spray the foliage of the plants occasionally and allow the water to trickle down onto the surface of the sand. This tends to keep the latter washed free of salts left by evaporation of nutrient solution at that point.

The particular advantages of the sand culture system of growing plants are, namely, low initial cost of installation; ease of producing seedlings; substantial freedom from soil diseases; porosity of sand, which allows roots to expand easily and furnishes good root aëration; ease of removal of the plants from the sand at any time during their growth, which enables them to be transplanted to other containers without destroying the roots; and, finally, the fact that sand serves as a sturdy support for the plant.

Fig. 10. Tomato Plant Grown in Sand (Eight Weeks from Seed) in Greenhouse in Winter. Nutrient solution was supplied to the sand. Note abundance and whiteness of roots.

One of the most important advantages of soilless growth in general is the almost complete absence of weeds and the common soil diseases. In soil farming, weeds must be continually removed, or they will otherwise rob the soil of its food and water so that the desirable crops suffer. Due to the fact also that, in water-growth, plants can be placed closer together than is possible in soil, the probability of weeds appearing, as well as of the acreage requiring attention, is less. Obviously, too, the diseases usually associated with soil-grown plants are not likely to be present in nutrient solutions. Due to the sturdier growth of water-grown plants they are more capable of "throwing off" diseases as well as insect pests. As pointed out in the preceding chapter, food deficiency often makes plants more susceptible to certain ailments. For instance, potash-hungry plants are more susceptible to plant cancer than those which are well fed.

As stated earlier, sand cultures may be adapted to practically any scale of operation. They may be used in the home in small pots or jars, or in the back yard in wooden troughs or tanks; or they may be carried out on a large scale in greenhouse operation (out-of-doors when climate permits) in large wooden, iron, or concrete troughs. These operations will be discussed more fully in later chapters.

Sub-Irrigation Method

This system of growing plants without soil resembles the sand method in that mineral aggregate (sand, gravel, cinders, etc.) is used as the medium of support. It differs from sand culture, however, in that the grain size of the mineral aggregate is generally larger, and the method of feeding chemicals to the plants is of a different nature.

Essentially it is carried on as follows: The set-up consists of a large shallow container, filled with mineral aggregate, in which plants are growing. At various intervals the entire tank is flooded with nutrient solution (pumped in from a

reservoir), which is then allowed to drain completely away, thus leaving the roots exposed to moist aggregate and air. After the roots have "aired" for a certain time, the system is again flooded with nutrient solution and the procedure repeated.

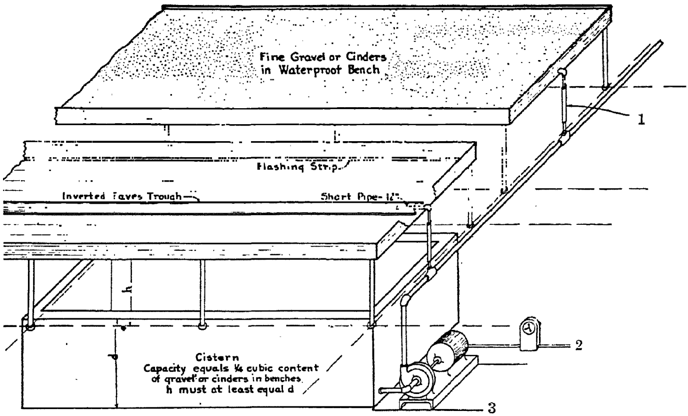


Fig. 11. Diagrammatic Sketch of Benches, etc., Employed in the Sub-irrigation System Utilizing Gravel, Cinder, etc. Nutrient solution pumped at intervals from drain pit beneath troughs.

1. Rubber hose connections, 1″ hose for $\frac{3}{4}$″ pipe, or $\frac{3}{4}$″ hose for $\frac{1}{2}$″ pipe. All pipe and fittings must be black iron, not galvanized.
2. Electric time switch. Three operations daily.
3. Centrifugal pump. Capacity: 20 gal./min./1000 square feet bench space.

(Courtesy Purdue University Horticultural Department and Florists' Review).

Experimenters at the Purdue University Agricultural Experiment Station, where the sub-irrigation system was originated (work was simultaneously being done on this method at the N. J. Station), propose a scheme of operation (Fig. 11) which is essentially as follows: The mineral aggregate is placed in

large shallow trays, the aggregate being from five to six inches deep. The trays can be of any convenient size, even up to several hundred feet in length. Beneath the trays is a food (nutrient solution) reservoir which serves also as a drain pit. By means of a centrifugal pump which is set off by an electric clock arrangement, nutrient solution is pumped to the growth tray overhead which contains the plants supported by the mineral aggregate. The pump operates until the tray is flooded with the nutrient material, which then flows, by gravity, back into the drain pit, or reservoir, below. The tray size and pump capacity are so regulated as to require about 40-60 minutes for the tray to flood, and about twice that time for the solution to drain. Then several hours elapse, during which the roots "air," before the cycle is repeated. The Purdue experimenters advocate about three floodings per day. Due to the fact that considerable evaporation occurs in the gravel or cinders used it is well to spray the entire tray with water occasionally (once each week or so) to remove accumulated salts left behind by evaporation.

The mineral aggregate used as support may consist of gravel, crushed stone, cinders, etc., of about ¼ inch diameter or smaller. It should, however, carry a low content of acid-soluble matter such as calcium carbonate (limestone), otherwise the acidity of the nutrient solution, which ordinarily stands at a pH (measure of acidity) of about 5 to 6 (mildly acidic), will be thrown out of balance. Moreover, precipitation of phosphates from the nutrient solution will occur on the surfaces of the limestone particles present and will be of little or no value to the plants. More than a few per cent of calcium carbonate or magnesium carbonate (limestone or dolomite), then, will surely lead to trouble. Marble chips obviously cannot be used since marble is of the same chemical composition as limestone. Quartz or siliceous gravel, granite chips, or cinders may be used satisfactorily. In the case of the latter material it is advisable to wash them thoroughly with dilute acid (followed by rinsing with water), prior to use, to remove soluble alkalies, etc. If concrete trays are used to hold the aggregate, the surfaces of the former

should be hot mopped with a high-melting petroleum asphalt (coal tar should be avoided), otherwise the alkalinity of the concrete will produce the same effect as would limestone. Some prefer to use exposed concrete tanks and add sulphuric acid occasionally to adjust the acidity of the solutions, but this, of course, necessitates an apparatus for measuring acidity.

In this or any other system of soilless growth the solutions should never be allowed to come in contact with zinc-coated surfaces. Since plants are poisoned by appreciable quantities of zinc, every attempt should be made to avoid contact with galvanized tanks or galvanized iron pipe. All pipes and pipe fittings should be of black iron. Rubber garden hose can in some instances be utilized to advantage in making pipe connections.

The principal advantages of the sub-irrigation method of growing plants are: good aeration of roots; ease of planting or transplanting; and the fact that it can be made entirely automatic, even in large-scale installations. After about each week or month, depending on its size, the reservoir can be emptied and fresh nutrient solution added. Aside from this operation, the system requires very little actual attention.

The preparation of nutrient solutions is thoroughly discussed in the chapter following. See Chapter Eight for a list of various formulas.

CHAPTER THREE

GROWING IN WATER

IN a preceding chapter a discussion was given on the functions of chemicals in plant life, how various elements are necessary for good foliage or healthy seeds, and how the soil ordinarily strives to supply the plant with the ingredients necessary for these functions. As will be recalled, also, an experiment was described in which a plant was removed from soil and placed in sand, and it was shown how the necessary chemical elements were furnished from external sources and how the plant continued to live and grow. Suppose, though, we should go a step further and even take away the sand and allow the roots to move about freely in the nutrient solution. Then it is to be expected that the plant would continue to grow as before, if provided with a means of support. Thus is formulated the basic principle of the water-culture method of growing plants.

WATER-CULTURE METHOD

As pointed out above, the technique consists essentially of suspending a plant above a nutrient solution and allowing the plant's roots to dip into this solution. It differs from the sand method in that the roots of water-cultured plants are capable of moving about in the solution. Naturally, there are numerous ways in which a plant may be supported above a solution, just as there are various containers in which the solution may be held. It is desirable to plan the individual set-up so that the level of the nutrient can be adjusted. In this, as in any other soilless growth system, means of aeration of roots must be furnished. In the sand and sub-irrigation systems this is cared for by the porosity of the aggregate. In the water-culture method, though, aeration is not so easily accomplished. For convenience of discussion, water-culture

systems will be divided into two classes, namely, those utilizing *"static"* (not moving) bodies of water, and those involving a continuous flow of nutrient, or a *"dynamic"* system.

Types of Containers

In both systems of water culture, wooden, glass, iron or glazed porcelain containers may be used. The plants may be suspended by baskets made of wire screen (preferably ungalvanized) of the proper mesh, which are hooked onto the rims of the containers. The plants may be held in place by excelsior, straw or other material of this sort, which is packed in to a depth of three to four inches. The solution chamber itself should be kept as dark as possible in order to minimize the growth of algae. If a glass container is used, then obviously its sides should be covered so as to cut out light.

In the *"static"* system, as its name implies, the body of nutrient liquid does not move, except by convection currents, and therefore does not have very good access to air. Aeration, then, may be effected simply by bubbling air through this solution occasionally or by merely lifting the basket supports at intervals so that the roots may "air." Although, as was stated, the solution normally moves only by convection, it may be found desirable in large tanks to aid this mixing by means of mechanical stirrers. Then, as food is used up over a period of a few days or a week or so, it will become necessary to replace the nutrient with freshly prepared solution.

The "static" and "dynamic" systems differ only as regards handling of nutrient solution. The jar, tray, or tank construction might well be the same for both. In the latter method the liquid is continually added and withdrawn from the region of the roots. In other words, the nutrient may be allowed to drip into the jar or tank from a reservoir and likewise recede to a drain basin. This possesses two advantages over the static system. First, in more exacting plant research, this enables a uniform concentration of food to be supplied to the plants (here the solutions may or may not be re-used), and, secondly,

by dripping through an air space, the solution carries dissolved air to the roots, thereby aiding aeration. In this way it would probably lead to somewhat better growth than is afforded by the static method. However, the dynamic set-up requires somewhat more attention than does static operation, since the former necessitates an occasional transfer of solutions.

The size and design of the set-up used will probably depend on the number of plants to be grown and the materials at one's disposal. If only a few house plants are desired, then an ordinary fruit jar, a gold-fish bowl, or other container will serve the purpose. If it is planned to produce vegetables for a family, one may use wooden or iron tanks or troughs for the purpose. A thorough knowledge of the principles of dirtless farming, coupled with a little ingenuity on the part of the experimenter, should lead to the desired results. It should be fixed clearly in mind, however, that in this sort of farming the experimenter must make sure that the substances ordinarily supplied by soil are fed to the plants, or else the results may be disappointing.

Plants by Water-Culture

In the growing of plants of the non-tuberous or non-bulbous types (for example, tomato, tobacco, corn, gardenia, etc.) a flat cover with evenly spaced holes may be placed over the nutrient container. Cork stoppers which have been split and reamed somewhat may be placed around the basal stalks of the small plants and then inserted into the holes of this flat cover. In this way the roots dip into the solution, and the plants may be lifted out all at once (by lifting the cover) or individually (by removing a single cork. Instead of split corks, wads of cotton may be wrapped around the lower stalks and wedged into the holes to support the plants.

Aeration Device

The authors have found that the simple apparatus of Fig. 12 furnishes good aeration and produces excellent results. In this,

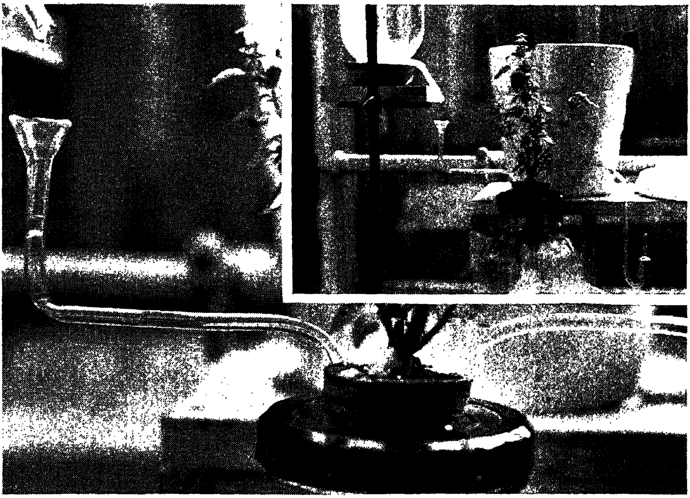


Fig. 12. Aeration Device for Water-culture Growth. Each drop of solution which falls from siphon tip (upper left corner) forces a slug of air down through tube, the air then bubbling through the solution in region of roots. Inset shows full view of set-up. Efficient aeration favors good root growth.

drops of solution, which fall from the tip of the siphon to the small glass funnel, force "slugs" of air into the tube and produce a continual bubbling of air through the solution in the immediate vicinity of the roots. In another instance the nutrient container may be covered by a wire screen made into a basket shape. The plants are in this way supported and their roots allowed to reach through the screen and into the solution below. It is assumed here that the small plants are produced from seed or by cuttings by methods described elsewhere in this book.

For the tuberous type of plant, it will be found that the basket support will probably prove most satisfactory, since it will allow more freedom for new tubers to form and expand.

But regardless of the type of support selected, the remaining features of the water-culture technique are more or less the same. When a small plant or sprouting tuber is first transferred to a water-culture jar or tank, the roots of the former will be small, both in size and length. Therefore at this stage the solution level must be brought up to meet the roots. The level of this solution is gradually lowered, however, day by day (the roots will be found to follow) until the proper air space is obtained. Instead of raising and lowering the nutrient solution level, the basket supports may be made adjustable so that the solution level can be held constant and the basket gradually raised during the early growth of the plant. It is not to be inferred from this discussion, however, that non-tuberous or non-bulbous plants cannot be grown in basket supports. On the contrary Fig. 13 shows young tomato plants, in the authors' laboratory, growing in a basket support.

Sprouting Potatoes

It is felt that a word should be added at this point in connection with a specific case of cultivation, namely, that of growing tuberous plants. As an example let us take the common Irish potato. In producing sprouts for planting, a potato tuber is cut into pieces so that each piece contains one or more whole uninjured eyes. These slices are next placed in sand or sawdust which is kept moist. In a short time "shoots" will pop through, and roots will lead off from the tuber. Now, at this stage the tuber is ready for transplanting. Let's assume that we are going to plant these in a wire basket support. Due to the fact that the roots are very short, the tuber should be placed directly on the wire and packed in with excelsior, etc. As the roots continue to grow and project down into the solution, however, the sprouted tubers should be gently raised, a little at a time, and excelsior slipped under them. This should be continued until the tuber is several inches above the wire, being careful never to take the roots completely out of the water. This manipulation is very necessary so that new tubers which

Fig. 13. Young Tomato Plants Shown in Wire-basket Support (in raised position) and Held in Place by Excelsior. The roots dip into nutrient solution.

will eventually form will do so above, and not below, the wire support. By inspecting the plants from time to time a mishap of this sort can be avoided.

Spacing of Plants

As for the spacing of plants in water culture there is no very definite rule. Perhaps it would be best to say, "Place them as close as you like." The only reason plants in soil have to be separated is that a certain volume of earth is needed to feed them. In soilless growth, however, since there is always an abundance of food at hand, one may arrange his plants with only a consideration of the foliage in mind. If this is over-crowded, then some parts may not get enough sunlight. In

growing flowers and vegetables it is probably not advisable to plant members too close together, because as they grow their general appearance might become that of being crowded and therefore be somewhat unattractive. Therefore it is left to the taste of the individual experimenter to decide how closely plants should be arranged.

In systems utilizing large tanks or troughs in which the solution is "static," aeration may be accomplished in two ways. First, an air space (of several inches) sufficient for partial aeration should be left between the bottom of the support and the top of the nutrient solution. A depth of solution of three inches is sufficient after the plant's roots acquire any appreciable size. As for introducing air into the solution proper, the most convenient way is to allow a stream of air to bubble through the solution for a few minutes each day. This will usually prove sufficient. In tank operation it is advisable to "flush" the system about once each two weeks. In this time most of the chemicals will be used up (if plants are sizable) and the acidity of the solution will have changed somewhat. As this system of growing plants is followed, the experimenter's technique will rapidly improve, so that he soon gets the "feel" of soilless growth and can usually tell sufficiently well what his plants need. When plants are small, their ability to use up food is correspondingly small, and it will not be necessary to replenish food as often as when the plants have gained considerable size. If a certain plant begins to ail, the experimenter can then turn diagnostician and supply to that plant just what it needs. A knowledge of these ailments and treatments can be gained by a thorough inspection of a later chapter, "Plant Detriments." Full directions for both the small-scale and the large-scale adaptation of soilless growth can likewise be found in subsequent chapters.

Watering Plants

Spraying and watering soilless-grown plants is necessary, as is the case with soil-grown plants. Spraying with water, as

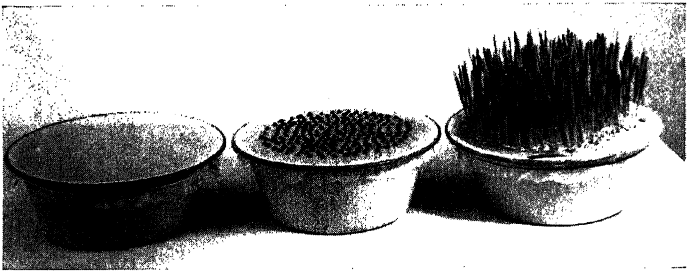


Fig. 14. Germination Net for Use with Nutrient Solutions. Seeds are placed on paraffined cheesecloth stretched over pan of diluted stock nutrient solution, the level of the latter being brought up to touch seeds. The seedlings may be easily removed and transferred. Sprouting by this method may be carried on in full sunlight provided solution level is not allowed to drop. Center, buckwheat seeds germinating; right, oat seedlings of convenient size for transplanting. (Courtesy J. W. Shive and W. R. Robbins, N. J. Agricultural Experiment Station.)

mentioned in an earlier chapter, serves to remove dust from foliage and therefore allows better breathing on the part of the plant. As water continually evaporates from nutrient solutions, this must obviously be replaced. A very advantageous way consists of spraying water onto the plant and allowing the former to drip into the solution below. This serves still another purpose, namely, keeping the plant base free of salts. Because of the tendency of a liquid to "wet," or spread over, a surface, nutrient solutions tend to creep up the roots and, by evaporation of water, to leave a salt crust on the base of the plant. Therefore if water is allowed occasionally to trickle down the lower stalk portion of a plant, the roots will be washed free of materials of this sort.

Just what results might ultimately be attained by this method are subject to much prophecy. Although "better than soil" results have not been obtained with all plants, a great number respond splendidly, especially the tuberous type, for

example, tuberous-rooted begonias, which often produce plants and blossoms of increased size. Perhaps the most astounding results thus far obtained are those of experimenters at a California university who succeeded in growing tomato vines 25 feet tall. In this case a very favorable climate no doubt aided materially. The amateur experimenter who enters this work will find it very fascinating once the common errors have been avoided and its simple requisites mastered.

The principal virtue of growing plants in water is that their roots have free access to solution and have to exert very little energy in expanding. In soil, growing roots obviously encounter extreme difficulty in forcing their way along, especially through hard dry soils, and the energy used up in piercing the soil is bound to detract from the normal growth of the plant in general. In some instances this "growing force" of roots is indeed tremendous. It is not an uncommon occurrence for a huge stone to be split open by the roots of a tree which had sprung from a tiny seed which at some time in the past had fallen into a crevice in the rock. You do not have to retreat to the woods, however, to find such an example. Have you not often observed the bulge of a concrete sidewalk which was laid too near the base of a tree?

In sand and cinder cultures very little resistance is met with by expanding root tips since these mineral aggregates are very porous. Nevertheless, only in true water-culture do roots have absolute freedom of movement. Convection currents cause a continual movement of the nutrient solution, and this means that the roots are ever coming into contact with fresh solution. Furthermore, when all other conditions of growth are the same, root systems in water-cultures are likely to be rather small because, as was stated earlier, root growth is governed by the scarcity of food and water. In other words, when food is scarce, roots have to work harder and therefore are longer than when food is near at hand.

Nutrient Solutions

Thus far, numerous references to nutrient solutions have been made, but very little has actually been told about preparing these solutions. As a matter of fact, it is a very simple task and is beyond the reach of no one. It is certainly as simple as the duties the amateur photographer performs in mixing solutions in his dark room. And there is surely less chance for error.

It was stated in an earlier chapter that if chemical elements are to be utilized by plants, those elements must be put in solution (dissolved) in water, and that such solutions must be brought into contact with the plant's roots. In soilless growth good contact between roots and solution is assured. Then only the matter of dissolving the chemicals in the proper way remains. First, these elements must be dissolved in suitable proportions (that is, so much potassium for so much nitrogen, etc.), and, secondly, the overall concentration must lie within a given range. For efficient growth, plants must have their roots subjected to very definite concentrations of fertilizing elements. Below this concentration food is not consumed rapidly enough by the plant, while larger concentrations of food chemicals tend to approach detrimental limits. The latter case depends on two factors. If too much food is available and is taken up too rapidly, it might be said that the plant develops "digestive troubles" and does not produce the type of growth most desired. Similarly, a "drying" action may be exerted, by too strong solutions, against the plant.

It is an accepted fact that sodium chloride, or table salt, is an important necessity in man's diet. Yet, if a person takes a heaping tablespoonful of this "harmless" substance all at once, it is likely to produce death. So it is with plants; practically any essential food becomes a poison if administered too freely. Very often a plot of ground may be rid of weeds by sprinkling ordinary rock salt over the soil. This, incidentally, carries other vegetation to its doom as well. On the other hand, plants

can tolerate small amounts of sodium chloride with presumably no harmful effects whatever.

Thus, it has been found that in the soilless growing of plants an overall chemical food concentration of about one part per thousand of water is within the limits of efficiency. This concentration may be varied somewhat, of course, but it must remain of the same order of magnitude.

Importance of pH

In addition to maintaining the fertilizing salts within certain limits of concentration, the acidity or alkalinity of the nutrient solution must be controlled. Here again certain slight variations may be made without producing drastic results. Ordinarily most plants require a pH value (see below) of 5 to 6 (a slightly acid medium) for best growth. Some, however, must be held slightly on the alkaline side at a pH of a little above 7. However, plants will grow outside of their pH range, although not as well as when the acidity or alkalinity is just right.

Just a word about this mysterious thing called pH. To the scientist it is recognized as a measure, or expression, of the acidity or alkalinity of a substance. All this is, of course, confusing, so we shall just say it is a measure of how acid or how alkaline a substance is and let it go at that. The pH scale for most purposes may be considered to range from about 0 to 14. Pure distilled water, which is accepted as being a neutral substance, has a pH of 7. Anything below 7 is acidic, whereas a material above 7 is on the alkaline side. Incidentally, the pH of human blood is practically 7 (neutral), and any attempt to change this value very much is certain to produce death.

As a rule one need not worry too much about acidity of nutrient solutions if they are changed occasionally. Assuming a freshly prepared fertilizing solution to have a pH of 5 initially, if after two weeks use this value had risen to 6 or 6.5, the solution could then be discarded and fresh solution of the proper pH supplied. For those who prefer to retain the acidity

or alkalinity within very narrow limits, several types of apparatus are procurable which give accurate measurements of these values. Although they may differ in design, basically they are more or less alike, that is, they rely on the production of color reactions of the solutions to be tested and comparing these colors with a set of color standards. More expensive apparatus of the electromotive type can be obtained, although the color-standard type is sufficiently accurate for this work. In actual operation, when the nutrient solution becomes too acid, it can be brought back by adding a small amount of caustic potash (potassium hydroxide). Similarly, if it is too alkaline, a little sulphuric acid will adjust the solution to the correct pH value. Caution!! Sulphuric acid or caustic potash must never be allowed to come into contact with the bare skin. In making dilute acid, the concentrated acid must be added, in small quantities, to an excess of water, *never* in the reverse order.

An inexpensive and rapid method of estimating pH values consists of using Nitrazine test papers, a vial of which can be bought through a druggist. A small color chart can be procured with the papers, which serves as a means of comparing colors produced on the test strips when the latter are wetted with nutrient solution.

Preparing Solutions

So much for concentration and acidity. What then about actually preparing solutions? Before we go further let us fix clearly in mind the fact that a given chemical element may be added in any of several chemical forms with equally beneficial results, provided, of course, those forms are soluble in water and do not carry with them poisonous ingredients. For example, potassium may be added as potassium acid-phosphate, potassium nitrate, potassium sulphate or potassium chloride, etc., and still be acceptable to the plant. Calcium, too, may be added as calcium chloride, calcium nitrate or in combination with phosphorus as mono-calcium phosphate. And so it goes

with the other fertilizing elements. It is even permissible to add certain elements which apparently do the plants no good, but, at the same time, which do not harm them either. For instance, due to cost considerations, nitrates may be added as sodium nitrate (Chile saltpeter). Of course, sodium is not essential to plant life and is therefore not used up. For this reason it is advisable to add some other chemical a part of which may remain to combine with the excess of sodium atoms. Thus, muriate of potash (potassium chloride) may be added together with sodium nitrate, as the former material is relatively inexpensive also. In this case potassium is consumed by the plant, but the chlorine remains behind to combine with sodium left from sodium nitrate, the nitrate portion of which is consumed. Thus sodium chloride is formed as a by-product and remains in the "spent" fertilizing solution. By selecting the proper ingredients for the nutrient solution, however, it is possible that no element is present which is not used up by the plants, so that no by-product salts remain after the fertilizing elements have been completely utilized. An example of this type is represented by Formula I, while Formula II (see Chapter Eight), is so prepared that both sodium and chlorine remain behind (as sodium chloride, table salt). Of course, it was stated earlier that sodium chloride (rock salt) was used to kill weeds. This is true; but the concentration of the salt substance formed as by-product in nutrient solutions does not reach detrimental limits, provided solutions are replaced occasionally.

Once the necessary salts have been procured in their proper amounts, there remains only the matter of satisfactorily getting them into solution. One cannot easily go wrong by dissolving each chemical separately in water and then mixing the dilute solutions. In this way salts remain dissolved, whereas some mixtures of salts in concentrated solutions lead to insoluble materials, or precipitates. Specifically, suppose we should prepare a nutrient solution according to Formula I (recommended by the N. J. Agricultural Experiment Station).

Formula I

Unit of Measure	Mono-potassium Phosphate KH_2PO_4	Calcium Nitrate $Ca(NO_3)_2.4H_2O$	Magnesium Sulphate (Epsom salt) $MgSO_4.7H_2O$	Ammonium Sulphate $(NH_4)_2SO_4$	Trace Elements
	Fertilizing Salt				
Grams per 5 gallons solution	5.9	20.1	10.7	1.8	(See below)
Teaspoonfuls (level) per 5 gallons solution (approximate)	$1\frac{1}{4}$	4	$2\frac{1}{2}$	$\frac{1}{2}$	

We start by dissolving each of the above chemicals in about a pint or quart of water. Then we mix the dissolved salts and add enough water to make 5 gallons. In order to provide the necessary "trace elements," we now dissolve together, in one pint of water, 0.8 gram (¼ teaspoonful) each of boric acid (crystals), manganese sulphate, and zinc sulphate. To each 5 gallons of fertilizing solution, as prepared above, we add 10 cubic centimeters (2 teaspoonfuls) of the boron-manganese-zinc (BMZ) solution. Since iron has a tendency to precipitate when mixed with fertilizing solutions, it is well to keep the former in a separate solution until just before use. For this we dissolve 0.8 gram (¼ teaspoonful) of ferrous sulphate (commonly called copperas) in a pint of water. Just before introducing to the plants, 5 cubic centimeters (1 teaspoonful) of this solution are added to each quart of nutrient solution. Ferric nitrate or chloride can be used as a source of iron, quantities of these salts needed being identical with that specified for the sulphate. In some instances the nitrate and chloride tend to remain better dissolved before use. In the above directions a teaspoonful quantity refers to a level measure.

As one must be rather careful about adding trace elements, so as not to get too much, the above quantities of trace elements are to be added only when purified fertilizing salts are used.

In case one desires to use commercial grade chemicals (these contain some trace elements as impurities), then it is necessary to add only about one-half the amounts of trace elements given above. For example, chemically pure mono-calcium phosphate costs about one dollar per pound. On the other hand some commercial grades of mono-calcium phosphate which contain a low percentage of fluorine (as fluorine is injurious to root growth, less than 1 per cent must be present in salts used) can be purchased, even in small lots of a few pounds, for as low as 5 cents per pound. This grade of salt contains about ten per cent of insoluble matter, but as this is not injurious, it may be disregarded, except that allowances must be made in calculating salt concentrations. If desired, these commercial salts may be dissolved, the insoluble matter allowed to settle, and the solution poured off and used.

It must be kept in mind in making up solutions, that *calcium* and *sulphates* must preferably not be brought together in concentrated solutions. This is because under such conditions some insoluble calcium sulphate is formed which precipitates out of solution. Although this material would eventually be redissolved in excess of water, its rate of solution is very slow indeed. This precipitation can be represented by a typical example as follows:

$$\underset{\substack{\text{Calcium}\\ \text{chloride,}\\ \text{soluble}}}{CaCl_2} + \underset{\substack{\text{Magnesium}\\ \text{sulphate,}\\ \text{soluble}}}{MgSO_4} \rightleftarrows \underset{\substack{\text{Magnesium}\\ \text{chloride,}\\ \text{soluble}}}{MgCl_2} + \underset{\substack{\text{Calcium}\\ \text{sulphate,}\\ \text{insoluble}}}{CaSO_4}$$

Thus, in a mixture of fertilizing salts containing, for example, mono-calcium phosphate, sodium nitrate, potassium chloride, and magnesium sulphate, either the first three salts or the last three may be dissolved together, but preferably the first and fourth should be dissolved separately. Under certain circumstances, soluble calcium salts (for example, calcium nitrate) may react with soluble phosphates (for instance, mono-potassium phosphate) to yield insoluble precipitates.

Assuming that one has chosen the proper chemicals in their proper proportions, there remains the task of getting them into the nutrient solution. A safe way, as mentioned earlier, is to dissolve each salt separately and mix in solution. In this manner, and by periodic replacement of solutions, one cannot easily go wrong. In some cases, however, the salts may be pressed into tablets, each tablet being sufficient for a given volume of solution. Then, depending on the size of the container used, a certain number of tablets may be dropped into the solution at various points throughout. Afterwards, over a reasonable period of time, an occasional tablet may be added to compensate for the food used up.

A method preferred by some consists of placing the necessary salts in a bottle or can into which are punched a few small holes. By diffusion, then, the salts are continually forced out into the surrounding solution. This method possesses the disadvantage, however, that insoluble precipitates are apt to form. In certain other instances in which time is a deciding factor, it is often permissible merely to sprinkle the powdered chemicals all at once into a tray or tank of water which is being vigorously stirred or agitated.

Although in Chapter Eight of this book is found a number of formulas for nutrient solutions, some of which are claimed to be better for one species of plants than for another, you are fairly safe in adopting any single solution and using it generally for most plants. In any event, the thing which must be kept in mind, and cannot be overemphasized, is just this: a steam engine cannot operate if it is not supplied with water and fuel, an automobile will not run without gasoline, and in precisely the same manner a plant cannot and will not grow without food. Although some difficulty is encountered whenever a person undertakes to master any new technique, soilless growth will respond favorably if given an even chance. If troubles do arise, the first thing to investigate is always the plant's diet. If that seems all right, check up to see if any toxic agents are creeping into the system and on the adequacy

of the aeration given it. (For more information about plant detriments see Chapter Seven.) Just remember that when a plant is entrusted to your care, you must treat it as you would treat a house pet, because, after all, the plant, too, represents life. You cannot maltreat it and expect it to thrive.

Extensive investigation has revealed that a surprising number of chemical elements have been found to exert a stimulating effect on plant growth. Some of these have been added to the roots, while others have even been sprayed on the foliage. Certain experimenters in soilless growth even recommend the use of some twenty-odd elements in the growing of plants. However, the authors feel that just as good results can be obtained, under ordinary circumstances, by using about ten elements as by the use of a much larger number. After the necessary, and a few beneficial, elements have been supplied, the use of still more would probably lead only to difficulty rather than benefit the grower.

"Spent" Solutions

As yet no very practical way has been found to recover and re-use chemicals from "spent" nutrient solutions. Due to the fact that elements are not always used up in the same ratios in which they are present, it is necessary to replace solutions occasionally. For this same reason the composition of "spent" solutions can be determined only by chemical analysis. This would ordinarily involve evaporating these solutions to dryness and determining the amounts of all the elements present. However, there is no need to become unduly concerned with this matter from an economic standpoint for the reason that, in any event, most of the fertilizing salts will be utilized by the plant. Furthermore, it will be found by anyone carrying on work in soilless growth that a few cents will go a long, long way in the fertilizing or food costs of growing plants.

CHAPTER FOUR

HOUSEHOLD PLANT CULTURE

THE principles involved in the manipulation of the three modifications of soilless growth, namely, sand, sub-irrigation and water cultures were discussed in the foregoing chapters. It is felt that more explicit directions for carrying out projects of this nature are needed at this point. Therefore, in this chapter will be included examples of soilless growth as designed for home use. In the next chapter more attention will be given to the large-scale operations of this type of plant cultivation.

Growing Flowers for the Family

The writers are not, at this point, attempting to suggest what, or how many, flowers to grow. That decision is left entirely to the reader. It will be attempted, however, to point out how flowers can be grown following the soilless techniques outlined herein. Neither is any demand being made for the exclusive use of any particular system of growing plants with nutrient solutions. All three methods have been presented impartially in preceding chapters. The reader, of course, will adopt the one he considers most practical for his own needs, and may even decide to grow flowers by all three procedures simultaneously.

Growing Flowers in Water-Culture

To initiate the discussion, suppose we start indoors. Usually there are several potted plants in almost every home, about the living-room or bed-room. In accordance with this, it will be noted that Figure 15 represents a very convenient arrangement (assembled by the authors) for growing flowers such

Fig. 15. Begonia Growing by Water Culture. Wad of cotton (not visible) holds plant in place in wooden ring. Photo shows plant in raised, or airing, position. Note massiveness of root system. This airing should be done only in the shade, and roots must not be allowed to dry. If solution is renewed once each week, this airing can be eliminated. Inset shows plant in normal position.

as the one shown (non-tuberous begonia). It is very inexpensive and easily assembled. One begins by purchasing a glass bowl, jar, etc., for only a few cents, and painting the outside of this container (or covering it with dark or heavy paper) so as to keep light away from the region of the roots (this minimizes algae; see also Chapter Seven). Next, a piece of wood, or other material, is cut in the proper shape to rest on the rim of the bowl. Into the inside space of this wooden ring is inserted the flower, around whose basal stem cotton is wrapped. The latter holds the plant firmly in position and at the same time is soft enough to allow free expansion of the plant's stem. One may start with a small cutting which has been rooted in moist sand or, if desired, a plant which has been removed from soil. The earthy material is first thoroughly washed away from the roots. The bowl is then filled with nutrient solution until the roots are at least partially immersed.

Airing and Watering Flowers

For aeration, the plant may be lifted out of the solution for a few minutes each day as shown in Figure 15. As the roots grow, the level of the liquid may be lowered, leaving them partly exposed to air. When this is done, however, it is well to spray the roots occasionally with water. As described previously, the nutrient solution has a tendency to creep up the roots, and when water evaporates from this solution, a salt film is deposited on the roots' upper regions. An occasional spraying of the latter with water will alleviate this condition. Then, too, as water is taken up from the solution by the plant (which takes up water more rapidly than it does salts), this must be made up by adding a little fresh water to the bowl each day or so in order to maintain a more or less constant level. One will find that a very convenient way to do this is to pour a little water onto the base of the plant (without removing it from the bowl) and allow it to trickle through the cotton mounting onto the roots and into the solution. This tends to keep the upper roots clean.

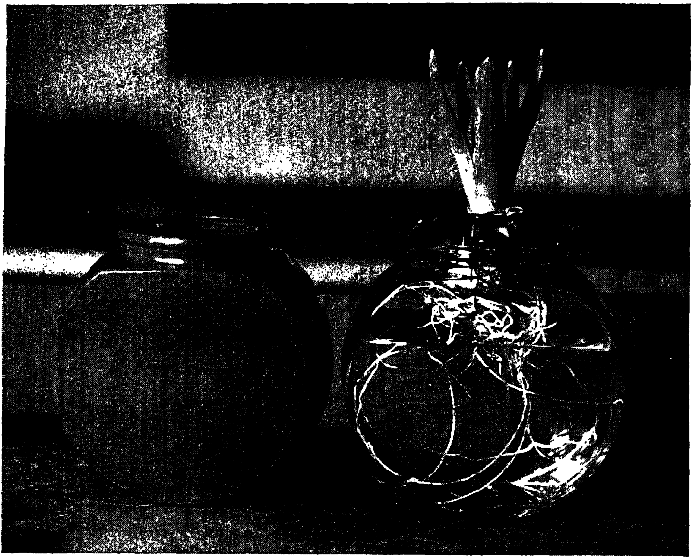


Fig. 16. Water-culture Arrangement for Bulbar or Tuberous Flowers. Wire supports should preferably be painted with asphalt or asphalt paint. Nutrient solution is replenished about once each week. The hyacinth shown above was originally in soil, later transferred to the above; it was finally grown to considerable height in the above arrangement (painted bowl) and flowered.

Making Supports for Flowers

In addition to the above bowl arrangement, bulbous plants have been successfully grown by water-culture in another set-up equally simple. This consists merely of a small wire basket, which may be constructed from wire screen, which fits inside the mouth of a glass bowl, being supported by the rim of the latter. The bulb is placed in the basket and then held in place by means of a little wadded paper or cotton. The nutrient solution level is then raised until it just touches the lower tip of the bulb. Figure 16 shows a hyacinth grown in

this manner. For the purpose of this photograph the plant and basket were transferred from the bowl on the left, in which it is normally grown, to the transparent one on the right, which permits an excellent view of the roots, etc. When the solution needs replacing, the basket and plant are simply lifted out while the growth bowl is being replenished.

The mineral-aggregate technique is just as adaptable to "parlor floriculture" as is the water-culture method. Using the same type of glass bowl or jar as previously, we may proceed to fill it with cinders, gravel, coarse sand, or pumice stone, etc., and insert the plant or plants in the customary manner. The nutrient solution is poured in until it comes within a few inches of the top, or until the capillary action of the pumice draws the solution up to the roots. This capillarity will be found to keep even the top lumps moist, although the actual liquid level is considerably lower. Porosity of pumice (or cinders) will also permit good aeration of the roots. As the plant and its roots continue to grow, the solution level may be gradually lowered to a reasonable point.

Of course, since the outside of the container is painted, the actual level of solution on the inside cannot be seen. However, by tapping the wall of the bowl with a pencil or coin, etc., from bottom to top, it will be found that the sound thereby produced abruptly changes as the solution level is passed. The directions for watering are simply to make up for what evaporates. When time comes to replace the solution, one hand is held firmly over the top of the bowl, thus keeping the aggregate in place, while the bowl is tipped slowly so that the old solution runs out. When the bowl is again righted, fresh solution is poured in. A scheme for emptying the bowl without moving it consists in pushing a glass tube to the bottom of the bowl (this tube need not be removed at all) and siphoning out the "spent" nutrient solution.

Growing Flowers in Glass Wool

Still another modification which has proved satisfactory con-

sists of combining the wire basket support with glass wool. (The latter can be used alone). Figure 17 shows a small fuchsia which has just been planted in a bowl utilizing this set-up. The method is very similar to that of the pumice bowl (see p. 65). Here, again, capillary action feeds the nutrients to the plant's roots. It is preferable to use inexpensive common soft glass wool rather than the more costly heat resistant types of hard glass wool as the latter might introduce too much boron into the solution, thereby poisoning the plants.

Fig. 17.

Small Rooted Fuchsia Cutting in Glass Wool containing Nutrient Solution. This fuchsia appears again in Fig. 19.

Figure 18 shows two fuchsias (left) in pumice, and two ivy geraniums (right) in glass wool. As mentioned earlier, roots must be kept in the dark to minimize fungus growths. Therefore in some of the accompanying illustrations transparent bowls are used solely for the purpose of a better photograph of the root support, but are not used in the actual growing of plants. Figure 19 represents a stage in the growth of four fuchsias, one being planted in pumice, another in glass wool, and two others in florist's soil. These were started from very

Fig. 18. Two Fuchsias (left) and Ivy Geraniums (right) in Nutrient-Solution Bowls. The fuchsias are supported in lump pumice. Geraniums are growing in glass wool.

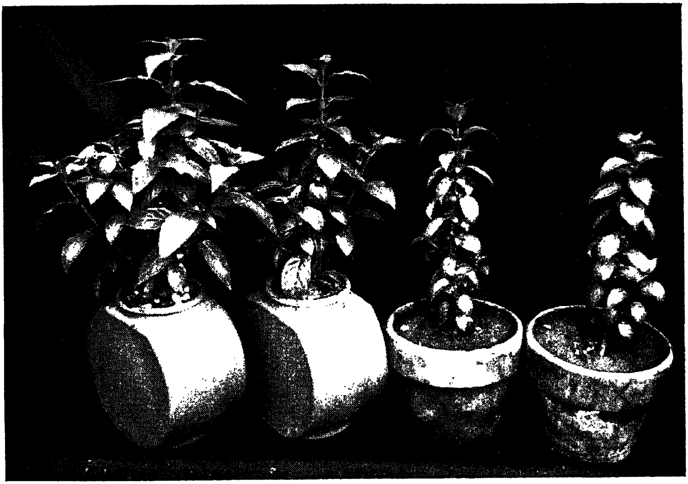


Fig. 19. Two Fuchsias in Soil (right) and Two by Nutrient-Solution Methods (left). One on extreme left is in pumice. Second from left is in glass wool. All were started as identical rooted cuttings, and none were pinched back.

small cuttings and were originally all the same size (about two inches in height). Simple bowl experiments such as those containing plants supported by glass wool or pumice require less attention than any that the authors have ever carried on. Food is changed once in two weeks and a little water added each few days. In certain instances plants in these supports have gone unnoticed for periods of a week without any appearance of damage. This is especially convenient for the family that must go away from home for a few days.

While the foregoing methods of growing potted plants serve to illustrate the fundamental principles, the reader will no doubt be able to devise many ingenious modifications of them, so as to utilize materials and containers on hand.

Growing Roses in Winter

The authors have obtained some very pleasing results by experimenting with roses. Ordinarily the home flower grower is concerned mainly with the growing of rose bushes out-of-doors during the spring and summer months, and in such places where the branches can be trellised along a fence or arbor. Generally, roses, in order to thrive, require very rich soil with a sufficiency of manure, and the latter would unquestionably be rather unacceptable in a living room. Yet, the authors were very successful in growing a rosebush in a home, using the sand-culture technique, at a time when snow was on the ground outside.

Roses were found to grow so well, under the conditions described above, namely, indoors and subjected to the usual dry winter atmosphere, that a few words are warranted at this time. Precisely, a dormant pruned-back rose plant (McGredy's Yellow) was removed from the soil on February 14, and, while showing no signs of activity, was transferred to a glazed flowerpot containing sand. From a one-quart reservoir the nutrient solution (Formula I, see Chapter Eight) was started dripping. This volume of solution was allowed to

Figs. 20 and 21. Two Photos of Rose Plant (McGredy's Yellow) in Nutrient Sand Fifteen and Thirty Days after Planting.

circulate twice daily. At the end of ten days the first signs of life were witnessed; a few small shoots appeared, just forcing their way through the surface of the old stems. The first picture (Figure 20) was taken on March 1, just fifteen days after planting. If carefully examined, this photograph will reveal one or two shoots about one-half inch in length. Once they had started, however, these shoots grew very rapidly. By March 6 (twenty days after planting) a small rosebud actually appeared. The second photograph (Figure 21) was taken on March 16, exactly thirty days after planting. At this time, or twenty days after the first shoot appeared, there were numerous new shoots, both large and small (several were 6-7 inches in length), on the bush. In addition, strange as it may seem, when the second photograph was taken (thirty days after planting), there were six small rosebuds on the bush. Despite the fact that it was being grown indoors, where no attempt

Fig. 22. Sand-cultured Rosebush (of Figs. 20 and 21) Six Weeks from Dormancy. In center is remnant of blossom which opened several days earlier.

Fig. 23. Rosebush (Eight Weeks from Dormancy) Grown in Greenhouse in Winter, using Sand-culture System (13 buds at time of photo). Species, McGredy's Yellow. Long stems make these roses particularly effective as cut flowers. Note partly opened bud in upper left.

Fig. 24. Simplified Sand-pot Arrangement. Solution is sprayed by hand spray-bulb over the surface of the sand several times daily. Pot is equipped with automatic constant-level siphon tube which requires no priming after initial flow. Solution is used repeatedly for several days (depending on plant size) before replacing.

was being made to maintain a favorable humidity or temperature, the plant appeared to be in the "pink" of condition. Figures 20 to 22 represent various stages in the growth of the plant, the photographs having been taken fifteen days apart.

Fig. 25. Simplified Sand-culture Experiment. Ordinary flower pot (with saucer) is filled with sand, and plant is inserted. Sand is first saturated with nutrient solution, and water sprinkled on as needed to keep sand moist. After several days or a week (depending on size of plant), water is poured in freely to flush system. Then fresh nutrient solution is added and cycle repeated. Coleus shown in photo was started as a small cutting in this sand pot.

A modification of the sand-pot set-up which will appeal to the person who doesn't care to bother with jars is that shown in Figure 24. In addition to the pot, a rest, and a catch basin, the only equipment needed is a rubber hand bulb. A few times each day (depending on the dryness of the atmosphere) a bulb of solution is withdrawn from the basin and sprayed over the surface of the sand. A little water now and then keeps the solution up to volume. The sand is fine enough to hold up the solution (available for roots) for considerable periods before the plant becomes thirsty.

Window Box for Soilless Growth

Those who wish to prepare a window box for either indoor or outdoor use will find that the one diagrammatically represented in Figure 26 is not only easy to start but requires very little attention as well. Although this one is designed primarily for sand or cinders, etc., obviously water-culture could be used with a few slight alterations. The nutrient solution in the reservoir is protected from the atmosphere and rain, etc., by the hinged flap. The chemical food flows through several short sections of capillary tubing (very small bore) spaced evenly along the length of the reservoir and through the bottom of the latter. This percolates downward through the sand and collects in the drain chamber, which is of the same capacity as the reservoir. By means of a simple rubber squeeze bulb with two oppositely faced valves such as one can purchase at a small cost, and a few short lengths of tubing, a handy return-flow device can be prepared. By a few squeezes of the bulb each day a sufficiently steady flow of nutrient solution through the sand can be maintained.

If sand is used as the support in this window box, then flowers can be planted in just about any stage of growth. Tiny seeds can be pushed just under the surface and allowed to germinate. Cuttings, for example, from growing plants may be planted in the sand, and, if partially protected from hot sun, will be found to take root very readily. Even indoors in

winter, specimens will become well rooted in a short time. The writers have found that cuttings, bulbs, tubers, etc., sometimes root more satisfactorily if placed directly in nutrient sand than if grown in sand kept moist with plain water. This seems logical, however, since the nutrient solutions contain all the chemicals that make for healthy root growth. Of course, bulbs and tubers carry a certain amount of "stored up" food and therefore will root in an inert medium and grow

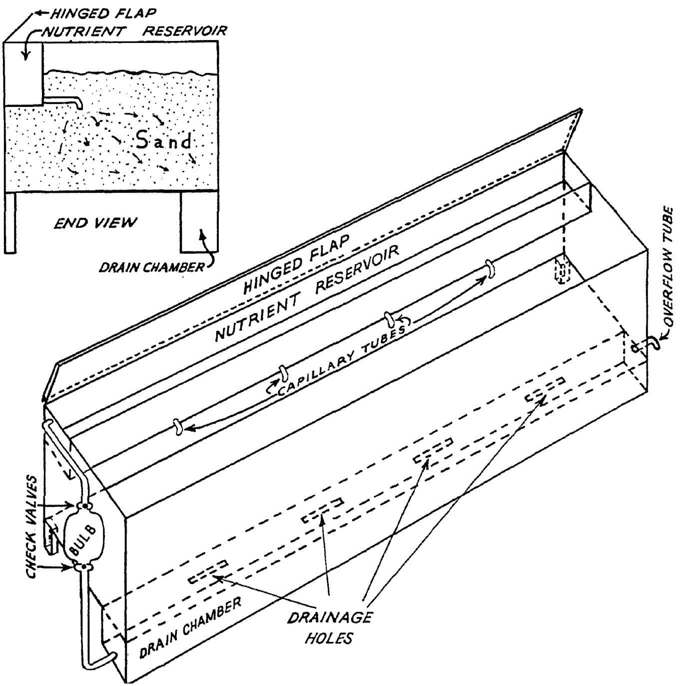


Fig. 26. Diagram of Window-box Equipped for Continuous Flow of Nutrients through Sand or Other Medium. Box may be constructed of wood or other non-toxic material. Galvanized containers and soldered seams should be avoided. Drainage holes are covered by wire screen to prevent sand from entering drain chamber.

for awhile. However, this auto-growth generally is of limited extent and is greatly supplemented by the presence of assimilable food. Small cuttings which have already acquired roots in soil, however, may be transferred to the window box, after soil particles have been washed away. On the other hand, if bulbous or tuberous flowers, such as tulips, tuberous-rooted begonias, etc., are desired, the bulbs or tubers can be planted in the sand to a depth known to be desirable for the particular specimen in question.

It is interesting to note that soil-grown and water-grown roots appear to be of a different nature. Thus, when a plant is removed from soil and placed in nutrient solution, or in sand or cinders and fed by nutrients, the plant is able to subsist satisfactorily because its soil-grown roots are capable of taking in water. However, it will be noticed that in a very short time new roots will appear at the basal stem of the plant, and that these roots are quite different in appearance from the earlier ones. Roots developed in nutrient solutions are very light-colored, in some cases appearing even transparent, as compared with the harder, more wood-like roots obtained in soil. It is not until these new roots appear that the plant begins to grow. It would seem in many cases that soil-grown roots are not capable of causing perceptible growth in nutrient solutions. When the news roots do appear, however, the soil-grown roots may be whacked off entirely with shears, leaving only the newly formed ones. Thereafter the plant grows in the normal manner.

Thus, within a very short time the reader can have the entire window box planted and everything under way. There is no messy dirt or odoriferous fertilizer to bother with, and at any time during the growth of a plant it can be removed or shifted around in the box without injuring its own roots and without harming any of the other plants. In addition, this window box of Figure 26 contains an overflow tube which will prevent the plants from being flooded during a rain. When excess surface water runs in, it merely overflows through

Fig. 27. Window-box of Fig. 26 Filled with Young Plants (Geraniums, Petunias and German Ivy). Reservoir has capacity of one-half gallon, and the solution is circulated once or twice daily. Seeds or cuttings may be germinated or rooted directly in this box. Rubber squeeze bulb (shown in photo) with oppositely faced check valves can be purchased as standard piece of equipment.

this tube. True, a little dilution of the nutrient solution may occur, although ordinary evaporation will return this to normal after a short time. Figure 27 shows the window box soon after planting.

Thus far, examples have been given for growing flowers in or near the house. Naturally these same principles can be extended to outdoor flower beds and arbors. It is felt that the reader can combine a little ingenuity with a proper use of available containers and materials and set up outdoor systems for growing flowers. Just keep in mind that, so far as is known, any plant can be grown by soilless-growth methods that will grow in soil in a given climate, and in very many cases larger plants can be obtained by the former method.

Beware of Sharpers

As will be discussed more fully later, the reader should not be victimized by high-pressure salesmen who attempt to sell them equipment (at exorbitant prices) for growing plants in water. Nothing is needed that cannot be constructed by the individual, or purchased at reasonable prices from reputable supply houses. In addition, you can buy and mix your own chemicals at a great saving.

By using the procedures outlined in this book one can produce lovely flowers year after year. Whether the summers be temperate or accompanied by severe drouths, uniform growths can still be obtained with nutrient solutions. Soilless-growth flowers probably will be free of all soil diseases and, in addition, free from a very common soil detriment in that insects which normally inhabit the soil during certain seasons will cause little or no trouble. This follows from the fact that in soilless-growth systems such insects would obviously be drowned. Even in many greenhouses florists are greatly troubled with beetle grubs which gnaw the underground stem of a plant and either stunt its growth or kill it outright. This condition is therefore eliminated in nutrient solution floriculture. In addition, due to the fact that soilless-grown flowers are generally very healthy, they may be expected to be in a much better condition to repel the onslaughts of plant-foliage pests and blights.

Methods of Propagation

As for propagating flowers, it was stated earlier that seeds could be planted in sand fed by nutrient solutions. A good rule in putting flower seeds in nutrient sand is to bury them to a depth equal to four times their own thickness. Extremely small seed, such as petunia, should not be covered at all (or else very slightly (but instead may merely be spread over the surface of the moist sand. In other words follow the same directions as would be given for planting in soil. Many persons often make the mistake of planting extremely small seeds

so deep that they are never able to force their way to the surface.

The same general rule should be followed in planting bulbs or tubers. If the tuber is customarily planted several inches under soil, as is the gladiolus bulb, then it should be rooted several inches under sand or cinders, etc. Tubers like that of the tuberous-rooted begonia, which must be only partly covered, are rooted accordingly. The flower grower will probably find it convenient to maintain at least a small sand box for germination and rooting purposes, even though the flowers are eventually to be grown by water-culture. In propagating flowers from cuttings, it will be well to refer to Chapter Six which includes a discussion of the use of root-growing hormones which are very helpful in producing roots rapidly from cuttings.

Growing Vegetables for the Family

Although flowers may successfully be grown either indoors (near windows) or outdoors, using nutrient solution methods, it will be found desirable to grow vegetables outdoors if possible. Recent newspaper articles have carried artists' impressions of the housewife opening the pantry door and picking enough vegetables for dinner. While this can absolutely be done, provided sufficient and proper light is furnished, it is more economical to do it outdoors if the space is available.

The Necessity of Proper Light

As a rule many vegetables require more sunlight than do some flowers, and, as a result, if the former are grown indoors, they may suffer because of insufficient illumination. As plants require a rather large quantity of light daily, and as most artificial lighting devices are rather inefficient, attempting to replace sunlight by man-made light becomes an expensive proposition. It is not to be inferred, however, that plants cannot be grown satisfactorily under artificial light. On the contrary, plants can be grown without any sunlight at all

Fig. 28. Effect of Rooting Cuttings in Nutrient Sand. A number of random coleus cuttings were divided equally into two groups. Those in top row were planted in a florist's regular cutting bed (moist sand). Those in bottom row were planted in sand fed by nutrient solution. This photo was taken twelve days after planting. Although coleus cuttings are easily rooted, substantial roots are more quickly obtained in nutrient media.

provided this form of energy is supplied by means of Mazda, electric-discharge, or other types of lamps. The expense of this practice, however, is too great for anything but experimental purposes.

Figure 29 illustrates how electric lighting is used in illuminating experimental plants. A small thermostat (temperature-regulating device), which was removed from an inexpensive fish-tank heater, was connected with the lamps. Suspending the thermostat just below the reflector serves to turn the lamps on and off. Heated by radiation from the lights, this thermostat breaks the circuit and turns off the lamps. On cooling, the thermostat again turns the lights on. Whenever

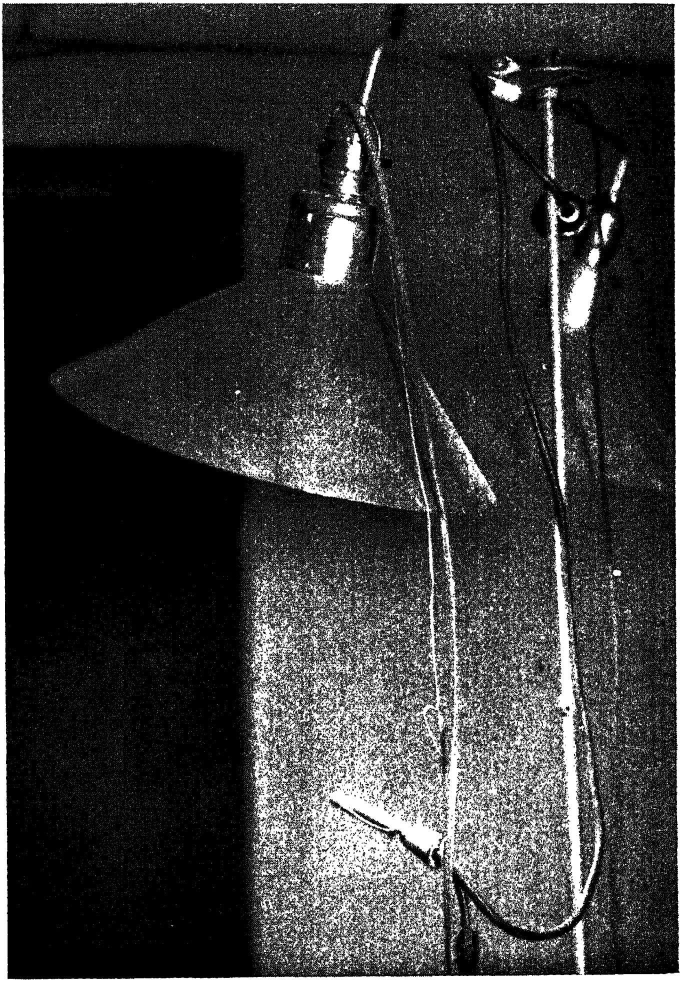


Fig. 29. Set-up Used in Authors' Laboratory for the Artificial Illumination of Plants. Note small thermostat suspended below the powerful lamps. The heat from the latter causes the thermostat to break the electric circuit intermittently.

strong lights are held close to plants, the illumination should be intermittent in order to avoid overheating of the foliage, which causes injury. The thermostat should be adjusted so that the lamps remain on for three to four minutes and off for an equal time.

Usually one can manage to find a few square feet of space in which to start a soilless-growth project. A tank can be placed on the ground, on the roof of a house or garage, or on any other structure with a flat top. It is not entirely too far-fetched to picture the "trailer tourist" of the future moving along the highway with his water-grown vegetable garden on the roof of his house-on-wheels.

The general rules for raising vegetables are essentially the same as those outlined earlier in this chapter for growing flowers. Here again it matters not what system of nutrient growth is adopted. The writers have tested all three systems and have obtained splendid results with each. Many people prefer simple water-culture troughs for the purpose, although it is advisable to have at least a small sand unit for germination purposes. On the other hand, still other experimenters prefer the exclusive use of the sand or cinder method of gardening. For example, radish or other seed can be planted very close together in a small container of sand, and, after reaching a convenient height, can then be transferred to large troughs or tanks. Potato tubers (slices) can be sprouted satisfactorily either in sand or in moist sawdust. After roots of suitable length (several inches) are acquired, the sprouts may then be transplanted.

Designing Tanks for Vegetables

Again, there is no set rule about the type or design of tanks or troughs to be used. Whatever the design, however, the container should be water-tight. If a trough is constructed of wood, by all means use screws and not nails in assembling the container. Caulking compounds containing lead or other toxic materials should be avoided. If constructed of, say, one-inch cypress and put together with screws, it should become water-tight of its

Fig. 30. Two Wooden Troughs (7×1×1 ft.) designed for Soilless Growth Projects. These are suitable for either greenhouse or outdoor work. The ledge near inside top supports wire baskets holding plants (See Figs. 31 and 32).

own accord within a few days after water is introduced. It should thereafter remain water-tight provided it is not allowed to dry out at any time. As an added precaution, the trough may be equipped with long bolts running through the ends so that minor adjustments can be made at any time. In addition, it does no harm to treat the seams and joints with hot asphalt, of petroleum origin. Obviously any such tank should be properly swelled with plain water before nutrient solutions are introduced.

In Figure 30 are shown two cypress troughs in the authors'

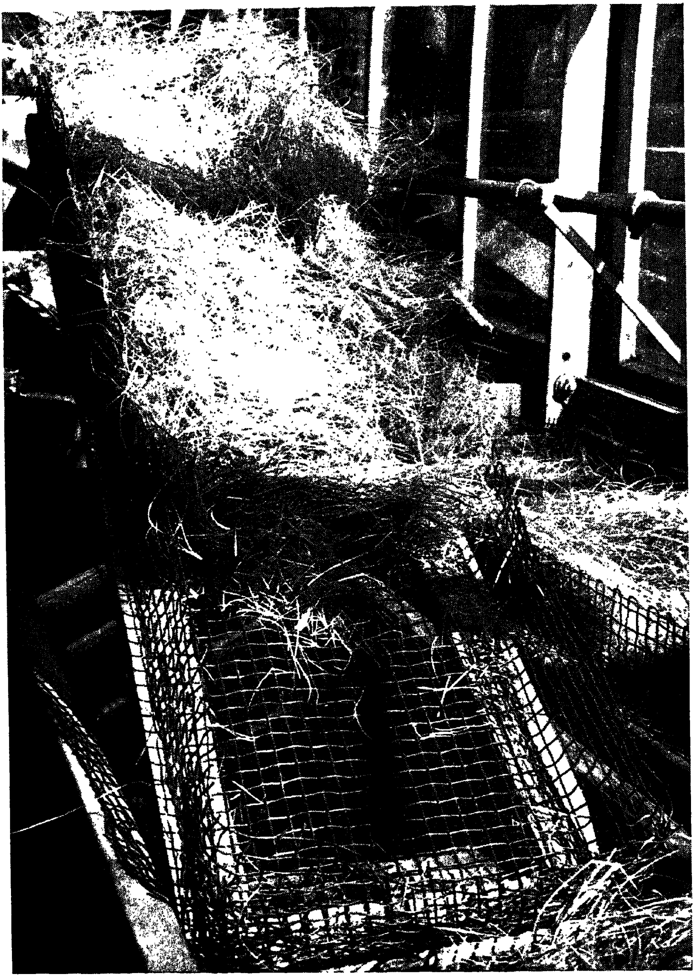


Fig. 31. Wire Basket ($\frac{1}{2}$-inch Mesh) Partly Filled with Excelsior. Any convenient mesh can be employed. Wire should be painted with asphalt before use.

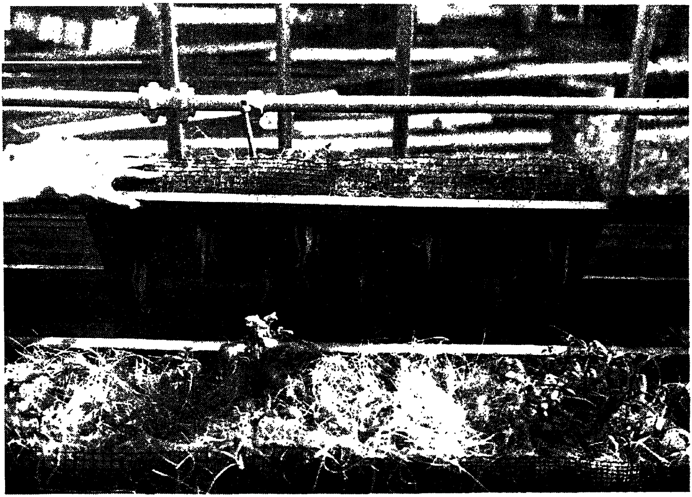


Fig. 32. Basket in foreground is in normal position. In background basket is tilted to show roots extending through wire.

greenhouse which were designed for water-culture experiments. These were assembled with four-inch screws, and no caulking compound of any sort was used. Each had a capacity of 25 gallons (level up to ledge shown) at time of planting. The solution was later reduced to about half that quantity. Figure 31 shows the type of wire basket used. Here it is shown filled with excelsior. Figure 32 shows one of these troughs after small plants had been inserted in place in the excelsior. All the young plants shown here were grown from seed, rooted from cuttings, or sprouted from tubers, in moist sand. When sawdust is used for sprouting purposes, it should be of a harmless variety. Pine sawdust is likely to carry too much pine pitch, turpentine, etc. Certain other woods (*e.g.*, some redwoods) tend to give off dyes, etc., which might be harmful.

Fig. 33. Tomato Plants Produced by Germination of Seed in Sand Supplied with Nutrient Solution. These are of a convenient size (4-5 inches) for transplanting.

The plants as shown in Figure 33 are of about the proper size to be transplanted for final growing. Although they do possess roots, these are nevertheless of rather small size. Therefore at this stage the solution level must be sufficiently high so that the roots are at least partially immersed. As the latter grow and extend downward, the solution level may be gradually lowered so as to maintain an air space in the root compartment.

Spraying Plants

As mentioned earlier, plants growing in nutrient solutions should be sprayed with water occasionally to wash away dust from the foliage; this allows better breathing. Occasional spraying of the roots as well (particularly the portions above the solution level) is to be recommended. Obviously, too, since water is continually consumed by plants and subsequently expelled into the atmosphere, fresh water must be added at intervals to the nutrient solution so as to maintain its concentration and level. The troughs shown in Figure 30 are equipped with drain pipes for emptying and adjusting the solution level.

As plants continue to grow, some form of support for the branches is recommended. A tomato vine, for example, is likely to produce so much fruit that the vine will be pulled down unless supported. This may be accomplished by tying it up on strings or sticks, etc. With proper care and feeding a tomato vine should attain considerable size in a few months. Figure 35 shows a group of tomato vines being grown at the New Jersey Agricultural Experiment Station in sand, using a continuous flow of nutrient solution. One gallon of sand is allotted to each plant. At the time of this picture they were over fifteen feet long, and each had produced twenty or more pounds of fruit. The frontispiece shows a close-up view of one of the sand-grown vines, showing the luxurious growth of tomatoes.

Aeration in Tanks

There remains, then, the question of aeration of water-culture plants and the changing of solutions. The authors find that the entire basket may conveniently be raised a few inches occasionally and allowed to rest on wooden blocks. In this way air can circulate among the roots. In addition, the nutrient solution can be "beaten" for a few minutes each day. This may be accomplished either by stirring the solution vigorously with a paddle made of stiff wire screen, etc. (an egg-beater is satisfactory), so as to cause intimate contact with air, or by

occasionally bubbling a stream of air (from a bicycle pump, etc.) through the solution.

At the present time the authors are experimenting with other methods of aeration. For example, certain aquatic plants (cabomba, water lily, etc.) are being maintained in water-culture tanks in order to determine if sufficient oxygen is liberated to aerate properly the other types of plants present. Another scheme being attempted consists of slowly adding hydrogen peroxide (drug store peroxide) to the nutrient solutions as a means of aeration. However, neither is sufficiently developed at this early date to be recommended for general use.

Tanks of the type described above are suitable for outdoor projects as well as for use inside the greenhouse. Figure 34 shows a number of such tanks on the roof of a city building.

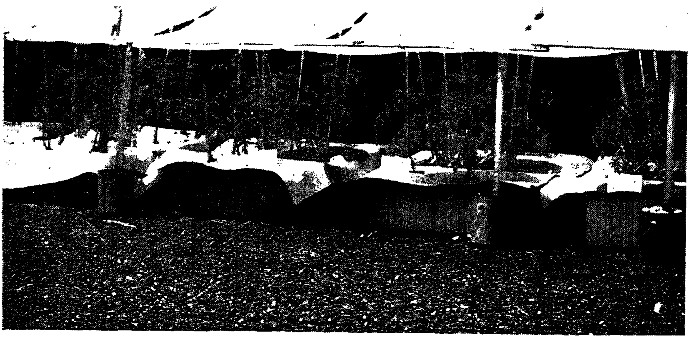


Fig. 34. Wooden Water-culture Tanks on Roof of Building. Tanks are covered with roofing material to prevent flooding in case of rain. Holes are cut in this roofing through which the stems of the plants pass. Cheesecloth covering overhead is needed only for those species which normally cannot tolerate full sunlight.

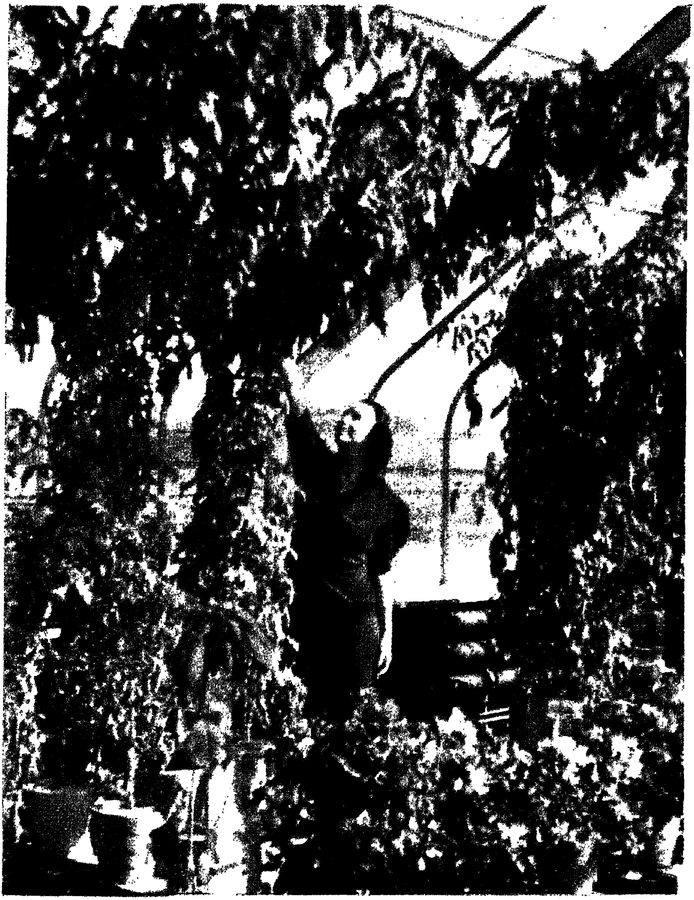


Fig. 35. Group of Sand-grown Tomato Plants (Marglobe Variety) at the N. J. Agricultural Experiment Station, using the Continuous-flow Method. These plants were about eight months from seed when this photograph was taken. Some vines had produced more than twenty pounds of fruit each. (Photo taken by permission of N. J. Agricultural Experiment Station).

These were assembled by the writers, and contain young tomato plants which are already beginning to produce fruit. A few such tanks as these will probably keep a small family supplied with vegetables.

When carrying out the water-culture technique, it may be found desirable in cool weather to add artificial heat to the nutrient solution chamber. This added heat will bring about considerably enhanced growth. For the purpose, a small aquarium heater (fish-tank heater) serves admirably. Electric heaters of the immersion type may be purchased for as little as a dollar or two. For greenhouse work during winter months, or outdoor work during moderately cool weather, when in either case the atmospheric temperature is about 50 to 60 degrees Fahrenheit, it may be found desirable to maintain the nutrient solution at about 70 to 75 degrees. In some cases this latter temperature may be even as high as 80 degrees but should not far exceed this.

Laticulture

Still another design of trough which has produced excellent results is that shown in Figure 36. Although only a little more than eight feet in length, it is, because of its odd construction, equivalent to a narrow trough twenty-five feet in length. Because of two long partitions which fit snugly to the bottom, nutrient solution, which is pumped in at one end, changes direction twice in traversing the twenty-five-foot linear distance and empties from the other end. Small dams at intervals throughout the trough serve not only to divide the latter into various compartments, but also to cause slower drainage of the nutrient solution. Small holes near the bottoms of the dams allow all the solution finally to drain back into a reservoir underneath, from which it was pumped originally. This method of nutrient culture the authors have termed "Laticulture." As a reservoir may be used a steel drum, the interior of which has been coated with a fairly hard petroleum asphalt. An ordinary hand pump is used in bringing the nutrient into the trough,

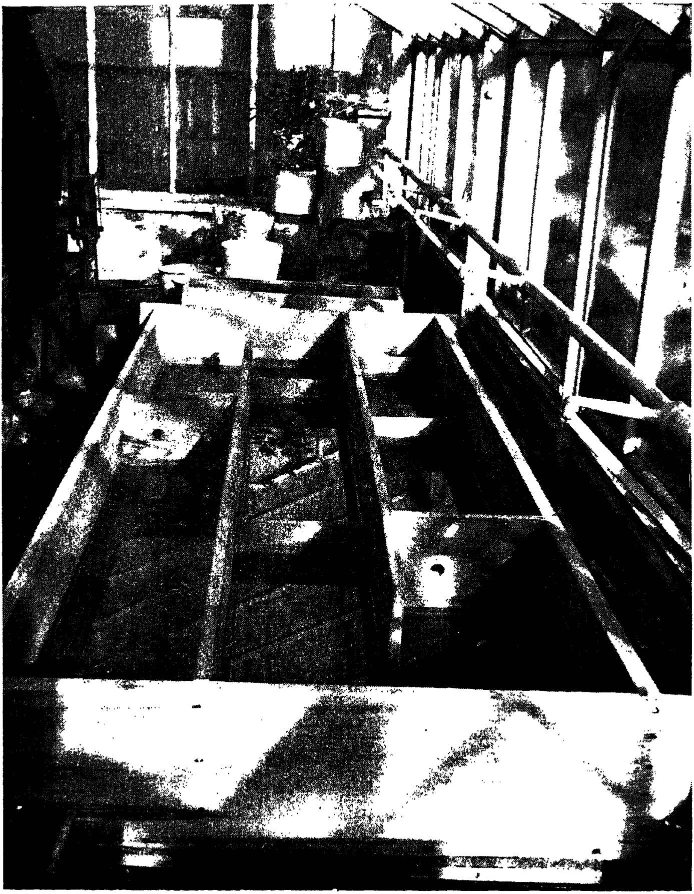


Fig. 36. Laticulture Trough being Swelled with Water before Introduction of Mineral Aggregates. Note construction and arrangement of partitions. Small holes (not visible) are bored near bottoms of dams to allow for complete drainage. Trough partly filled with water at time of photograph. Note: Apparent criss-cross in bottom of trough is reflection of roof of greenhouse.

Fig. 37. Trough of Fig. 36 shortly after Planting. Cinders, sand, etc., were used as aggregates. Trough is flooded with nutrient solution twice daily with a hand pump which delivers solution from drainage tank beneath trough. Solution is completely replaced once each week. In foreground are seen radishes, lettuce, spinach, etc.; in background, tomatoes and potatoes. Potatoes in upper right reached height of 4 feet in ten weeks (from tubers).

the solution being introduced two or three times daily and at alternate ends of the trough.

In this form of container, different mineral aggregates may be used. For example, sand may be placed in one compartment, whereas cinders may be used in another, and gravel in still another. In this way seeds or cuttings may be germinated or rooted in sand and later transferred to cinders when size permits.

In the trough shown in Figure 36 and again in Figure 37 the authors planted tomatoes and potatoes, radishes, spinach, celery, lettuce and asparagus, and, as flowers, gladioli, carnations, and snapdragons.

With a view to developing techniques applicable for use by persons residing at seashores, etc., where soil is scarce and water is not altogether free from probable dissolved matter, the authors are supervising soilless-growth experiments being carried on in Key West, Florida. In this locality certain seasons of the year afford surface waters which tend toward brackishness. Therefore this type of water is being tested in nutrient solution experiments for determining its efficacy in growing plants without soil.

Simplified Aggregate System

As stated previously, in carrying on any of the soilless-growth techniques described earlier, one is not limited to the several methods of manipulation described in this book. A very simple method that can be followed, but which probably will not give as good results as can be obtained by continuous flow methods, consists of the following: Plants are started in a pot, tray, or trough of sand or cinders which is equipped for drainage. At intervals of several days sufficient nutrient solution is poured or sprayed onto the aggregate so that the latter is wetted throughout. Then, once or twice a day thereafter a little fresh water is sprayed over the aggregate to compensate for that lost from the solution by evaporation, etc. As water evaporates from the solution, the nutrient tends to migrate

toward the top of the aggregate. Thus an occasional spraying with water will keep this washed down onto the roots. Then, at intervals of about a week, after which time the plant food will have been substantially used up, water is sprayed freely onto the aggregate so as to "flush" the system thoroughly. After this the feeding, etc., is repeated, and so on.

This system requires a minimum of equipment, although, as stated, the results might be somewhat poorer than those obtained from continuous flow methods. As will be described more fully in the chapter following, this simplified technique has been used with good results in a fairly large greenhouse project in the growing of sweet peas and certain other flowers.

There is one precaution worth remembering. In harvesting or removing plants from sand or cinders take care to remove as much of the root system as possible. For example, in removing full-grown radishes from sand, pull gently so that the roots do not break away. The removal is greatly aided by pouring water into the sand as the radish is being pulled out. The reason for this bit of care is simple. As long as roots are a part of a growing plant, they will not deteriorate under normal conditions. As soon as these roots are torn away from the parent stalk, however, they begin to decay whether they are in water, sand, cinders, or soil. Naturally, when this putrefaction sets in, substances are produced which are not beneficial to good growth.

Plan Work at Small Expense

It was stated earlier, and will be re-emphasized here, that one need not go to any great expense to carry on soilless-growth projects. On the contrary, the writers strongly advise the amateur experimenter to improvise his own trays or tanks and to mix his own chemicals.

It seems that whenever any new technique is introduced to the public, there is always a certain amount of ill-planned exploitation which goes with it. A leading weekly news magazine recently carried an item on "tank farming," brand-

ing it as a hoax and warning the public to beware of high-pressure salesmen who try to sell equipment for growing flowers and vegetables in water and promise miraculous results. The authors are clearly aware that this sort of thing is going on, and, as well, that soilless-growth chemicals may be offered for sale at fancy prices. In spite of this, however, there is no need for the reader to be victimized in this manner. The advice, then, is (1) build your own containers from materials at hand and (2) purchase commercial grade chemicals from a chemical supply house at a very nominal cost and mix them yourself, using the simple "teaspoon" directions given in a later chapter. If in doubt as to the identification of a chemical supply house consult your telephone directory or a commercial buyers' guide. It is not implied in the least, however, that all concerns engaged in selling supplies for soilless growth are unreliable. On the contrary, there are no doubt more than a few companies selling the equipment who, in addition to being content with reasonable profits, refrain from making preposterous claims for this method of growing plants.

Prominence of Soilless Growth

That soilless growth is a "coming" item is indicated by the following facts. (1) There were two impressive exhibits of soilless growth at the New York Flower Show held at the Grand Central Palace, New York City, in March, 1938. (2) The National Resources Committee in 1937 selected "Tray Agriculture" as one of the most important technical developments of recent years. The authors realize, too, that "cheap" exploitation of a new technique is the surest way of "nipping in the bud" what otherwise might lead to fundamental developments in human welfare. They have knowledge, too, that certain of these salesmen are telling the unsuspecting public that by using their (the salesmen's) chemicals, plants grow without light. This method of selling chemicals can produce only one thing, that is, a large number of dissatisfied customers who will thereafter crusade against soilless growth.

It is true indeed that if soilless growth is carried on by a person who is willing to devote some time and consideration to it, it will very often be possible to grow plants superior to those of soil, but it cannot be done under conditions that are definitely detrimental. It requires time and attention, just as soil-grown plants do, and, in addition, common sense. But these pleasing results cannot be obtained by merely putting a plant in a jar of nutrient solution, pushing it back into the closet, and forgetting about it until harvest time. Chemicals or no chemicals, plants still require sunlight (or its equivalent) in order to grow, and if you doubt this, you may prove it to yourself to your own sorrow. Should the authors, at some future time, become involved in manufacturing soilless growth materials, they are nevertheless interested primarily in giving the reader a straightforward and unbiased picture of soilless growth.

CHAPTER FIVE

COMMERCIAL ASPECTS

WHENEVER a new or different practice is developed to the extent of being turned over to the public for actual use, it is, in many cases, rather slow to gather momentum. Some of those who attempt a new procedure will meet with failure, others will be rewarded with success. But if the good points are there, sooner or later they are bound to be brought out.

Such has been the case with soilless growth. It was first learned some time ago that plants could be grown in nutrient media. For a number of years plant chemists in experiment stations and universities carried along research on this phase of plant physiology. It was not until a very few years ago, however, that the art had progressed sufficiently to demand public attention. Of late, there has been a rather sudden, and widespread, interest shown in this method of growing plants.

Progress in soilless growth has followed the course normally pursued by any new operation. In putting any laboratory experiment into large-scale practice, the broad gap must be covered in several successive and intermediate steps.

Establishments in Operation in the United States

During the past year several soilless-growth projects have been initiated throughout this country. Greenhouse operators here and there have become aware that perhaps opportunity is trying to knock at the door, and they have begun converting sections of their houses to accommodate nutrient solution techniques.

Some of these operators are highly elated over both the ease of operation of, and the results produced by, soilless growth. Some have expressed the desire to abandon soil alto-

gether and work entirely with nutrient benches. Others of the greenhouse people are moderately enthusiastic, expressing the belief that the best promise of soilless growth lies in its ability to produce more uniform crops year in and year out.

In this country at the present time several establishments are engaged in producing flowers, vegetables, etc., by nutrient solution methods. A number of greenhouses in the middle-western United States, specifically, in Illinois, Indiana and Ohio, are growing *cucumbers, sweet peas* and *stocks,* etc., using the sub-irrigation system. It is reported that a water-culture farm was established on the coast of Maryland for producing tomatoes. A rather large outdoor water-culture establishment in Fort Lauderdale, Florida, is producing *corn, tomatoes, peas, melons,* etc., and numerous flowers and palms.

In New York State an outdoor soilless-growth plot was in operation during 1937 for the production of tomatoes. A greenhouse concern in New Jersey has had very good success in growing *sweet peas, stocks, carnations, snapdragons* and *lupins.* A large greenhouse establishment in New Hampshire is likewise investigating growing plants without soil.

Just to what point in commercial practice soilless growth will ever progress cannot be safely predicted. Whether or not the day will come when the farmer will harvest his corn in a rowboat is not a matter of greatest importance just now. There is a strong possibility, however, that the time is not too distant when the man in the greenhouse will abandon soil and produce plants exclusively by nutrient solution methods. The farmer will find soilless growth extremely valuable for early production of seedlings for field setting.

Work Abroad

Abroad, considerable research in soilless-growth methods is being carried on under the supervision of the Russian government. It is reported also that a water farm is being set up on Wake Island for the purpose of supplying fresh vegetables to the Pacific Clipper Ships.

Failings of Soil

There are several definite objections to the use of soil in greenhouses. In the first place greenhouse soil must be regularly replaced, generally at least once a year. This involves considerable expense in transporting the old soil away from the house and spreading it on an open field to "rest" for a few years. Then, new soil must be procured and transported back into the greenhouse benches. These operations constitute one of the largest single expenses of greenhouse operation.

Secondly, most soils are not fertile enough to produce hothouse-variety plants without liberal applications of fertilizer from time to time. Although soilless-growth methods require fertilizing salts, these could probably be used to better advantage in the soilless system.

The soils in most greenhouse benches do not receive as great an amount of surface water as does outdoor soil. For that reason root excretions tend to accumulate which sooner or later may cause trouble through self-poisoning.

Another, but by no means an insignificant, objection to soil is the problem of soil diseases. Dead organic matter in soil constitutes a splendid medium for the growth of fungi and detrimental bacteria. The relative cleanliness of soilless-growth methods tends to eliminate most of these parasitic agents.

Advantages of Soilless Growth

The particular advantages of nutrient-solution techniques for greenhouse work are as follows:

1. Soilless-growth methods allow closer planting (abundance of food), thereby conserving space, the thing most precious in hothouses.

2. Relative freedom from common soil diseases which are carried by decaying matter in soil. Freedom from soil-inhabiting insects. Freedom from weeds.

3. Larger yields produced by soilless-grown plants. Attention is called here to tomato vines grown at the N. J. Agri-

cultural Experiment Station, some of which are at present fifteen feet tall (and still growing) and have produced in excess of twenty pounds of fruit per vine.

4. Assurance of consistently uniform crops, year after year.
5. Simplicity of operation and ease of controlling systems by electrically operated automatic pumps, valves, etc.
6. Ease of starting young plants and removing old ones.
7. Cleanliness.

As indication of some of the actual large-scale projects being carried on at the present time with soilless-growth procedures, the following cases are offered.

Flowers, etc., by Nutrient Solutions

In West Chicago, Illinois, George J. Ball, Inc., is carrying on some interesting work with *stocks* and *sweet peas,* using the sub-irrigation method. The experimental work is carried out with rather small units, a number of which are shown in Figure 38. A very simple method of feeding consists merely

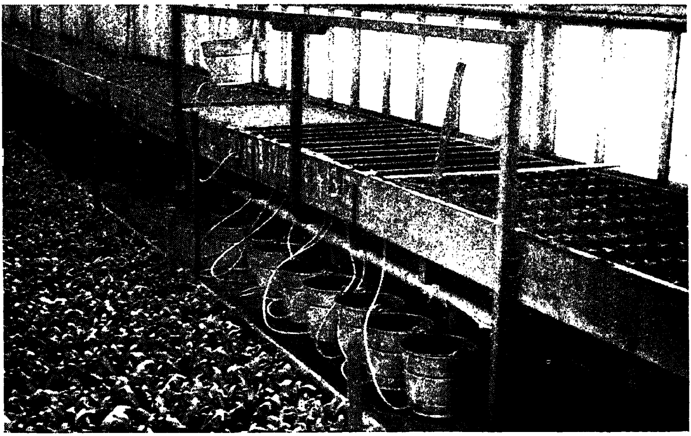


Fig. 38. Experimental Gravel Benches, showing Bucket Arrangement for Irrigating Growth Chambers. (Courtesy Geo. J. Ball, Inc.)

Fig. 39. Section of Long Gravel Trough, showing Arrangement of Aggregate. Fine material is layered over coarser river gravel. Nutrient is pumped through inverted eave in center and flows evenly into gravel. (Courtesy Geo. J. Ball, Inc.)

of raising and lowering the buckets of nutrient at intervals. These solution containers are connected by means of rubber tubes with the troughs in which experimental plants are being grown. In the elevated positions, the solutions are forced through the beds of mineral aggregates. When the solutions are to be withdrawn, the buckets are merely returned to their original positions beneath the benches. A number of different nutrient solutions are being tested by this concern in an attempt to find those best suited for the particular plants in question.

The (large-scale) production-size benches operated by Ball, Inc., are of a construction represented by Figure 39. The long narrow troughs are one foot wide and six inches deep. Along the bottom center lies an inverted eave through which nutrient solution flows and from which it is distributed to the entire

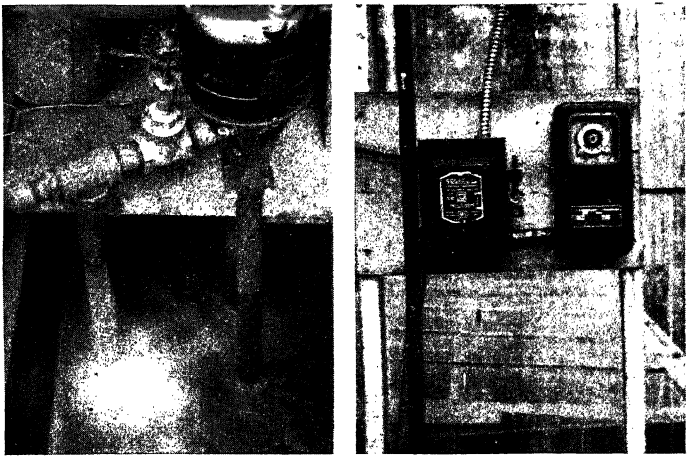


Fig. 40. Centrifugal Pump (left) and Electric Time Switch which starts pump three times daily. After pump is cut off, nutrient solution flows slowly back into drainage chamber under the gravel benches, where it remains for further use. (Courtesy Geo. J. Ball, Inc.)

system. A layer of coarse gravel is spread over the bottom to a depth of two inches, the top four-inch space being filled with aggregate of smaller size. When the benches are in operation, solution is pumped from a reserve tank by means of a centrifugal pump automatically regulated by an electric time switch (see Figure 40). Figure 41 shows young *stocks* and *sweet peas,* respectively, being grown in long gravel troughs.

After carrying on soilless-growth work in 140-ft. benches for some time, Ball, Inc., wrote the following:*

"Growing plants without soil—a laboratory dream of several years ago—now even threatens to remodel our entire flower production industry. While the project is clearly in its infancy, yet progressive greenhouse men all over the country are taking an increasing interest in it."

* Grower Talks, Vol. 1, No. 9, published by George J. Ball, Inc., Jan., 1938.

The expense of installation, equipment, electricity, etc., for the sub-irrigation system has been estimated at 2 cents per square foot per year. This small additional cost (greenhouse

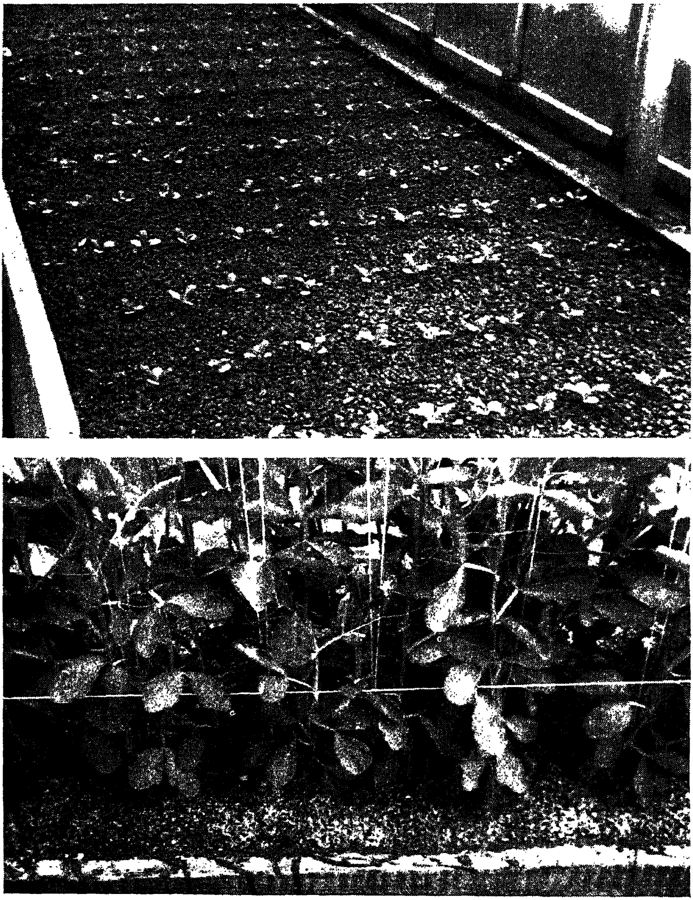


Fig. 41. Two Views of Large Benches showing Young Stocks (upper) and Sweet Peas (lower). (Courtesy Geo. J. Ball, Inc.)

Fig. 42. Plots of Sweet Peas (above) and Wall Flowers and Calendulas (below) produced by Sub-irrigation Culture in Mineral Aggregate. (Courtesy Albert F. Amling Co., Maywood, Illinois). (Photos by Carleton Ellis, Jr.)

maintenance ordinarily runs around 60 cents per square foot per year) is more than overcome by improved yields of crops and decrease of manual labor.

Cucumbers by Soilless Growth

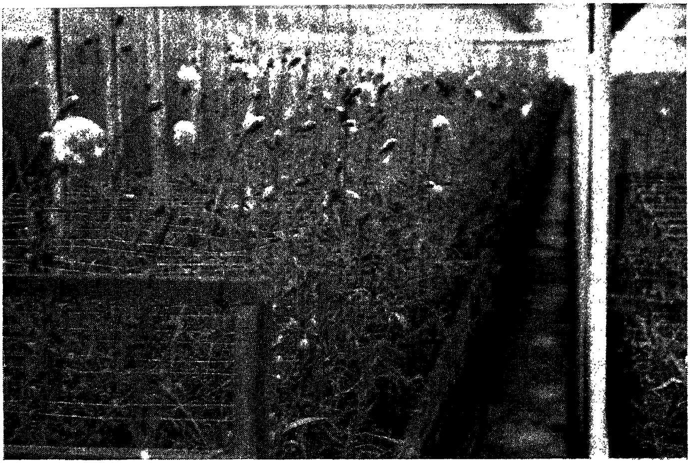
Cucumbers are a species which for some time was not believed to be adaptable to soilless-growth systems. However some very interesting work along these lines is being carried on by the J. W. Davis Co., which maintains extensive greenhouses at Terre Haute, Indiana. In this establishment cucumbers are being grown by the sub-irrigation technique. Figure 43 illustrates very clearly the results which they have obtained in one of their cucumber projects. Note the large cucumbers hanging from the vines.

Other midwestern concerns known by the authors to be using the sub-irrigation method of culture are Yoder Brothers Company, Barberton, Ohio; Albert F. Amling Company, Maywood, Illinois; and William A. Hansen Company, 620 South Wabash Avenue, Chicago, Illinois.

Sweet Peas, Carnations, etc., in Cinders

In West Orange, N. J., Gustave Freytag and Son, Inc. has several soilless-grown flower species on production scale. At this establishment a modified mineral aggregate technique is employed, and very good results are obtained. Plants are grown in long benches of cinders, the beds of the latter being about 12-15 inches deep. The benches are not water-tight, and no attempt is made to have them so. Once each week nutrient solution is sprayed onto the cinder bed until the latter is thoroughly wetted with nutrient. Then, every day or so, water is sprayed over the aggregate to prevent the cinders from becoming dry. At the end of one week the entire system is flushed out thoroughly with running water (this washes away accumulated root excretions) and allowed to drain. After a few hours' time fresh nutrient solution is added to the

Fig. 43. Color Photo of Cucumber Vines Being Grown by the Sub-irrigation Method of Soilless Culture. (Photo taken by E. B. Hodge, by permission of the J. W. Davis Co., Terre Haute, Indiana).



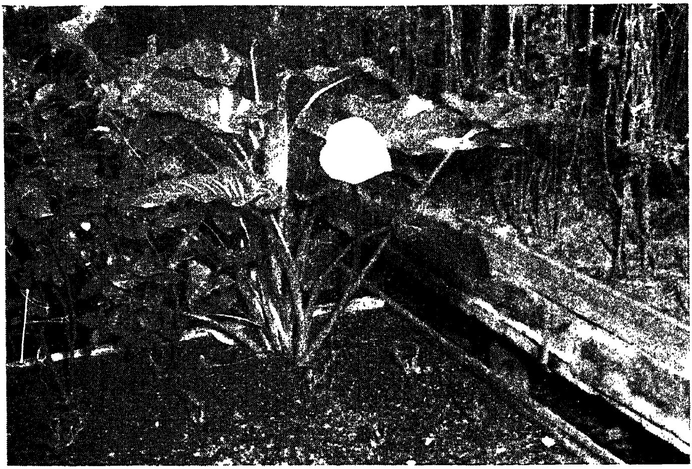


Fig. 44. Benches of Carnations (above) and Callas and Roses (below) Growing in Gravel by the Sub-irrigation Method. Note large white blossom in lower photo. (Courtesy Albert F. Amling Co., Maywood, Illinois). (Photos by Carleton Ellis, Jr.)

cinder bed, and then the entire process is repeated. Using this scheme, the Freytag group have produced flourishing *sweet peas, lupins, carnations, snapdragons, stocks,* etc. Incidentally, Formula I as shown in Chapter Eight was fed these flower species.

Figure 45 shows sweet peas growing in troughs of cinders. In Figure 46 are plots of carnations and snapdragons which were grown by the cinder method just described.

The preceding modification of the mineral aggregate set-up is just one of many possibilities. Probably somewhat better results would be obtained using water-tight troughs with regular (two or three times daily) floodings with nutrient solution. This "static" cinder method (staticulture) does point out, nevertheless, the relative ease with which plant growth in cinder aggregates may be carried on. Possibly other just as simple plans may be in operation throughout the country, and undoubtedly many such systems will appear in the future.

Trees Grown in Nutrient Solution

Apparently there is no restriction on the size of plant that may be grown by soilless-growth methods. The authors have used the sand system in germinating seeds as small as, or even smaller than, some of the sand grains. The foregoing examples demonstrate the applicability of nutrient-solution methods for the growing of flowers. Corn and grain crops have been satisfactorily grown without soil. There are, in addition, several instances in which fruit trees have been grown in nutrient solution. At the N. J. Agricultural Experiment Station peach and apple trees are being grown in cinders fed by nutrient solutions. Although there are perhaps a number of plants where propagation has not been attempted by soilless-growth methods, there is no doubt that adequate nutrient formulas could be worked out for their efficient growth (Fig. 47).

Trans-oceanic Gardens

The authors have conceived the idea of constructing soilless-

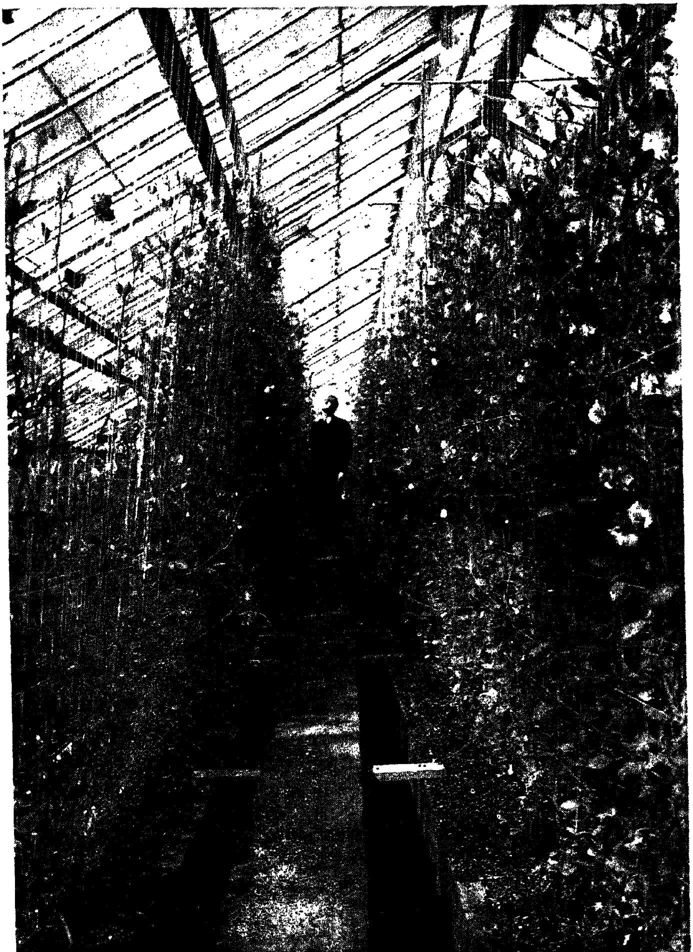


Fig. 45. Sweet Peas growing in Benches of Cinders Fed with Nutrient Solution. (Courtesy Gustave Freytag & Son, West Orange, N. J.)

Fig. 46. Carnations (right) and Snapdragons (left) growing in Cinders. Note: Soil-grown potted tulips in left foreground. (Courtesy Gustave Freytag & Son.)

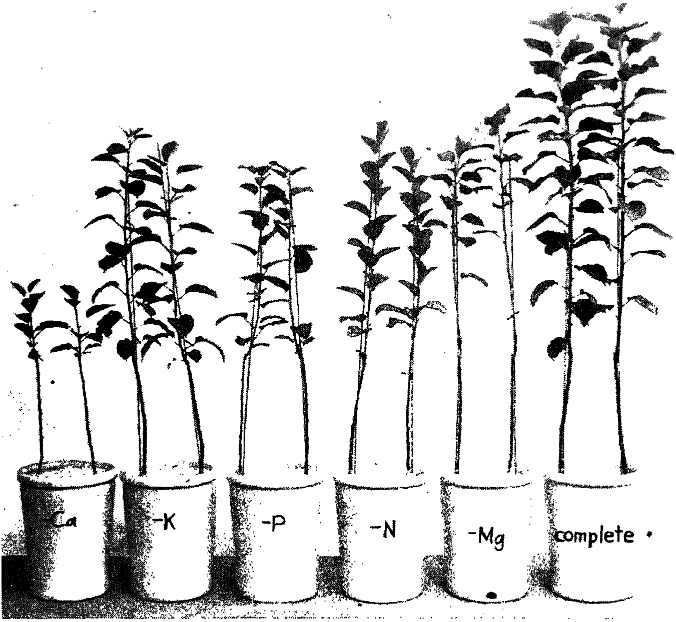


Fig. 47. Young Apple Trees Growing in Sand Fed by Nutrient Solutions. The trees on extreme right were fed properly balanced food. To the other five jars were fed nutrient solutions deficient in various elements as indicated. Reading from left to right, the following elements, respectively, were missing: calcium (Ca), potassium (K), phosphorus (P), nitrogen (N), and magnesium (Mg). (Courtesy M. A. Blake, N. J. Agricultural Experiment Station).

growth gardens on board ships and other conveyances. For example, by means of such a nutrient solution set-up constructed on the deck of an ocean liner, the passengers could be supplied with fresh vegetables and flowers during lengthy voyages.

The same idea of having moving gardens is likewise worthy of consideration by the trailer tourist. Portable troughs might

serve well for the purpose of producing a few vegetables or flowers.

In the authors' greenhouse, experiments are being carried on along this line at the present time. An electrically powered

Fig. 48. Wooden Trough equipped with Rocking Mechanism to Simulate Movement of Ship at Sea. This set-up used in studying effect of continuous movement on plants. In this trough, which is filled with cinders and sand, are planted carnations, colei, tigridias, onions, potatoes and tomatoes. Trough is flooded with nutrient solution twice daily.

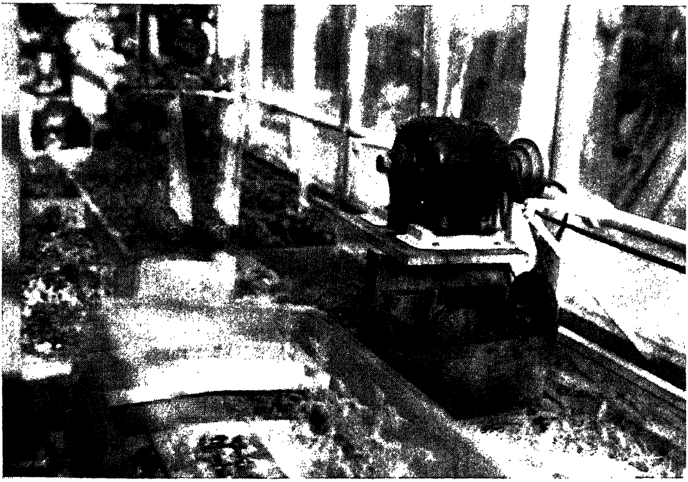


Fig. 49. Multiple-exposure Photograph to Show Rocking Movement of Trough.

rocking device, with adjustable speeds, was constructed for the purpose of rocking a long wooden trough. Figures 48 and 49 show this mechanism and its method of operation. Various types of plant supports are being tested in this apparatus in order to determine those best suited for rocking motions, that is, what types of aggregates, etc., will cause a minimum of root injury due to grinding. The entire mechanism was designed so as to simulate the rocking of a ship. The variable speeds allow the conditions of either a rough or a calm sea to be duplicated in the greenhouse. As will be noticed in the photograph of the rocking trough, baffles are spaced at various distances in an attempt to study further the shifting of supporting media.

Though the young plants shown here have successfully withstood constant rocking for quite some time, the authors prefer not to make any definite recommendations at present as to the most desirable materials for the purpose.

CHAPTER SIX

SPECIAL CHEMICALS

ALTHOUGH the main body of "special materials" discussed in this chapter is organic in nature, that is, of animal or vegetable origin, it is felt that some further mention should be made in regard to the mineral elements ordinarily associated with plant growth.

From the standpoint of plant life as treated in this book, a "special chemical" may be considered as any substance, simple or complex, which materially affects the life processes carried on by a growing plant. According to this definition, all those chemical fertilizing elements utilized by a plant in the process of growing would automatically fall into this class. And rightly so, because from a material standpoint, hormones (see below), in the restricted sense, would be of little value if it were not for the more commonplace supporters of plant life, the fertilizing elements. However, for the sake of differentiation, the fundamental fertilizing elements will be excluded from the "special chemicals" consideration.

Boron as a Possible Hormone

It is felt, however, that the reader should be reminded of the role that boron is believed to play in the sexual fertilization of certain blossoms, and of the adequacy of traces of this element in the diets of all plants. Certainly, too, manganese, zinc, etc., which bring about enhanced growth of plants, must deserve consideration beyond that of being a mere plant food. Very recently, too, it has been reported that selenium, an element highly toxic to animals, is absolutely essential for the growth of certain species of the *Astragalus* genus (legume crops) which refuse to grow in soils devoid of selenium. The latter has been suggested as a possible hormone.

Plant Hormones

Plant hormones are generally regarded as complex organic substances which govern, or materially alter, the courses normally pursued by a growing plant. In the human body there are hormones that affect the skin, the weight, sexual reproduction, and countless other things. So it is with plants, for here too we find that the development of a given plant, during its entire life, is controlled by various plant hormones.

In writing this book we have attempted to steer away, so far as possible, from complicated chemical discussions or intricate diagnoses of physiological processes within plants, and to avoid other highly technical discourses which would tend only to confuse the reader or cause him to lose interest. In spite of this, however, hormones are, to say the least, complex chemical substances, some of whose structures are not too clearly understood even by the scientist. Although we shall endeavor to continue our practice of presenting facts in non-technical language, the reader's indulgence with us through certain parts, such as that which we are about to enter, is respectfully solicited.

Mechanism of Plant Growth

As mentioned earlier, plants grow as the direct result of two cell functions. First, some cells divide, and, secondly, other cells stretch. In the tips of growing plants, cells are continually dividing, and the result is that the tip extends or "grows." In the regions below the tip are those cells which have resulted from division of other cells. Those resultant cells continue individually to grow, with the net result that the plant as a whole grows. Now, these tip cells *divide* because of a particular reason, and that is because there are hormones present that make them divide. Similarly, the reason that cells below the tip *stretch* is because there are certain hormones present that cause them to do this.

Removing Hormones by Cutting Tips

It stands to reason, then, that if the tip of a growing plant is cut off, the stem should cease to grow. This is found to be the case, but if the proper hormone is then applied to the cut surface, the tip again resumes its growth. This cessation of tip growth by cutting off the extremity of a plant is the basic reason for pruning plants. By this practice, then, a more bushy plant (with more numerous buds) is generally produced.

Sources of Hormones

A great number of animal and vegetable products are now known to contain plant hormones or "auxins," as they are generally called. Perhaps one of the most prolific sources of plant auxins is human urine, which was discovered by Kögl about 1931 to contain several such growth promoters. He found that each one million parts of human urine contains about two parts of combined auxins. These include auxins *a* and *b* (both very complex chemical compounds) and hetero-auxin (beta-indoleacetic acid). All human urine, regardless of the person's sex, age, or pathological condition, contains these auxins, although their relative proportions may be somewhat influenced by diet. Chinese duck yoke is also a rather convenient source of these auxins, although the concentration is considerably lower: 1 part in 3½ million parts of yolk.

In view of the discovery of growth-promoting substances, or hormones, in urine, one is impelled to call to mind the "good earth" farmer who persistently refused to give up his stable manure for "store bought" fertilizers because he "knew" that the manure was better. In this connection it is interesting to note that Liebig, a well-known German chemist, working in the latter part of the nineteenth century, was strongly ridiculed when he put forth the belief that certain small traces of impurities are responsible for cell-division in yeast cultures. At about the same time in England Charles Darwin first brought forth the original concept of the hormone theory of plant movement as accepted today.

Minute Amounts of Hormones Effective

The miraculous part about hormones lies in the fact that such inconceivably minute traces are capable of bringing about such drastic changes in the behavior of plants. Something less than one-trillionth of an ounce of one of the urine auxins was found by Kögl to give a visible reaction. The way in which plant hormones are tested is essentially as follows: An almost microscopic section is removed from the stem of a tiny oat seedling (*Avena sativa*) and, while maintained in a culture medium, is treated, on one side only, with the auxin in question. Since the latter material is applied to only one side, the cells in that portion will naturally grow faster than those not coming into contact with the hormone. Thus, the seedling section will be found to bend away from the hormone-treated side. Measurement of the angle of bending gives a direct indication of the activity of the auxin substance tested, this activity being expressed in "Avena units."

For the sake of those who may be interested, the urine auxins *a* and *b* are complex organic acids possessing the formulas $C_{18}H_{32}O_5$ and $C_{18}H_{30}O_4$, respectively, and structurally are very similar to the human sex hormones. Hetero-auxin or beta-indoleacetic acid possesses the formula $C_{10}H_9O_2N$.

Root-Growing Hormones for Cuttings

Still another plant hormone, beta-indolebutyric acid ($C_{12}H_{13}O_2N$), has been found to possess marked root-stimulating qualities. Considerable work has been done on this material at the Boyce Thompson Institute for Plant Research (Yonkers, N. Y.) and is of especial value in stimulating root growth on difficultly rooted cuttings. This should be of particular interest to the flower grower, both amateur and professional, who encounters difficulty in rooting certain plant cuttings. At the present time beta-indolebutyric acid is sold on the market under several trade names. By the proper application of this substance a much larger percentage of cuttings can be made to take root than is possible without its use.

Fig. 50. Effects of Hormones on Plants. Group A. Three tomato plants; left, untreated; middle, treated with 1 part of illuminating gas per 1 million parts of air; right, treated on upper side with naphthaleneacetic acid in lanolin. Group B. Two tomato plants with tops removed. Left, untreated; right, upper end of stem treated on cut surface with naphthaleneacetic acid in lanolin. Note drooping of leaves and locally induced root growth. Groups C and D. Taxus and Dahlia cuttings, respectively, showing rooting of cuttings with and without treatment with Hormodin A (indolebutyric acid). (Photo by courtesy of P. W. Zimmerman, Boyce Thompson Institute for Plant Research, Inc., Yonkers, N. Y.)

Apply Hormones Cautiously

On the other hand these plant hormones must be applied with due precautions. Although small amounts bring about the desired results, larger quantities may well become toxic. For instance, University of Chicago scientists found that when beta-indoleacetic acid was mixed into a lanolin paste and rubbed on the stems of plants, in some cases increased growth of the plants resulted. In other instances, however, plant

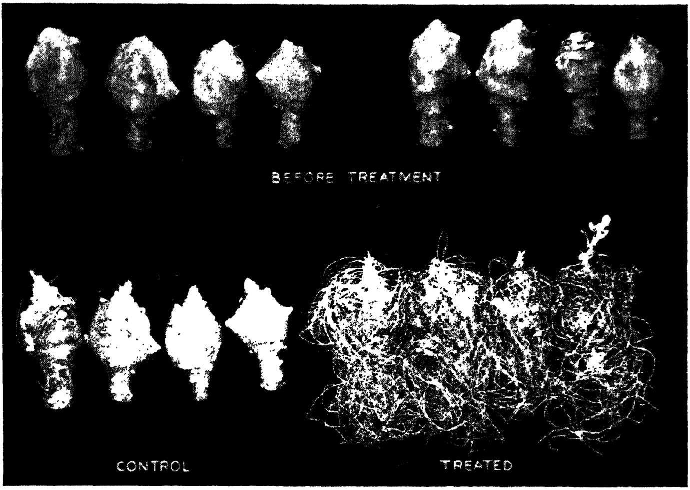


Fig. 51. Jerusalem Artichokes, showing Effect of Treating Tubers with Growth Substance, Naphthaleneacetic Acid. Upper row represents eight similar tubers. Four tubers on left were treated with pure water; those on right were treated with 1:10,000 naphthaleneacetic acid in water. After treatment all were planted in sand. After twenty-one days they were removed and photographed a second time (lower row). (Photo by courtesy P. W. Zimmerman, Boyce Thompson Institute for Plant Research, Inc., Yonkers, N. Y.)

tumors, wilting, and other malformations could be produced at will. It was found further that indoleacetic acid is often associated with certain plant ailments such as crown gall, corn smut, etc. Other organic compounds which have been found to act as plant hormones are *indolepropionic, phenylacetic,* and *naphthalene acetic* acids.

Sexual Function of Hormones

A very recent discovery of considerable importance has resulted in the controlled production of seedless fruits, vegetables and,

incidentally, flowers. If very dilute solutions of beta-indoleacetic acid (some of the other hormones act in this manner) are sprayed onto unpollinated flowers, an artificial sexual fertilization is produced. The tomato responds in this way. Another experimenter has found that when substances soluble in chloroform are extracted from pollens and sprayed onto unpollinated blossoms, growth is initiated in the ovaries of the latter, which in some instances leads to seedless fruits.

It might be added that *skatole,* an indole compound resembling some of the plant hormones, and occurring in human feces, likewise possesses the ability to accelerate the growth of roots in cuttings. On the other hand thyroid extracts (animal hormones) decrease root growth and produce stunting of the leaflets of certain seedlings.

Urinized Peat

In connection with this discussion on hormones and root-promoters, etc., some mention might be made concerning investigations carried on by the authors. Although urine contains certain plant hormones, it is nevertheless very toxic to plants if added directly to them. Therefore, urine hormones are ordinarily isolated, by means of complicated procedures, in a fairly high state of purity before being applied to plants. The authors, however, allowed a fairly large quantity of human urine to percolate through a bed of peat moss. In this way auxins were taken up by the moss, whereas most of the constituents of the urine were carried away. A small quantity of this "urinized peat" was then added to a nutrient solution in which sweet-potato plants were being grown. Another set of plants was grown under precisely the same conditions, but without urinized peat. The temperature of the nutrient solutions was held at a constant value by means of thermostatically controlled immersion heaters. Figure 52 shows the vast difference in root growth as produced by peat treated with urine. The plants in the jar on the left were fed nutrient solution similar in all other respects to that of the jar on the right.

Fig. 52. Root Growth of the Sweet Potato Stimulated by Urine Constituents. The untreated plants (left) were grown in nutrient solution without root stimulants. Jar on right received urinized peat.

Doubling Chromosomes and Producing Large Flowers

Chromosomes, in plants as well as in animals, are the minute units which are present in the nuclei of germ (sexual) cells and attach themselves to the genes (the somewhat smaller bodies which transport characteristics from generation to generation). Their combined purpose is to fashion the traits and hereditary characteristics of the offspring, in other words, to control such factors as plant size, shape, productivity, etc., and, as well, the type of tissue of which the plant is composed.

It has been observed in nature, in rare instances, that doubling of chromosomes has occurred, though perhaps accidentally. This often produces offspring of changed characteristics such as, for instance, larger size. It is believed that in some cases severe climatic conditions may be responsible for this occasional doubling.

Colchicine Active Agent

However, it was not until 1937 that a method was revealed for the controlled and consistent doubling of chromosomes in plants by artificial means. Dr. A. E. Blakeslee and co-scientists working at the Carnegie Institution of Washington, Department of Genetics (Cold Spring Harbor, Long Island) are responsible for this phenomenal work with a chemical called *colchicine*. This complex alkaloid, found in the roots of the well-known meadow-saffron *Colchicum Autumnale,* was found to possess the unique ability to cause doubling of chromosomes. Prior to this time presumably colchicine was used only in the medical profession where it served in treatment for gout, etc.

Effects of Colchicine on Foliage

When very dilute solutions of colchicine are sprayed onto the foliage of plants, a characteristic roughening or crumpling of the leaves occurs. This is the result of unequal growth within, due to the fact that a new type of tissue is produced by the colchicine treatment. This new tissue grows at a different rate

from that of the tissue initially present in these leaves and produces malformed plants in the same generation in which treatment takes place. Some plants may be altered to such a degree that they never reach the flowering stage. Those "affected" plants that do eventually flower, however, will be found to possess some seed of increased size, and increased chromosomal number. When examined under the microscope, pollen grains from plants whose chromosomal numbers have been doubled will be found to be twice the size (volume) of pollen grains produced by the plant before colchicine treatment.

When these first-generation seeds are germinated, they give rise in that, and in succeeding, generations, to well formed plants of considerably increased size. In some instances this chromosome doubling may be carried on several times in succession. Figure 53 shows Datura blossoms of four types. These

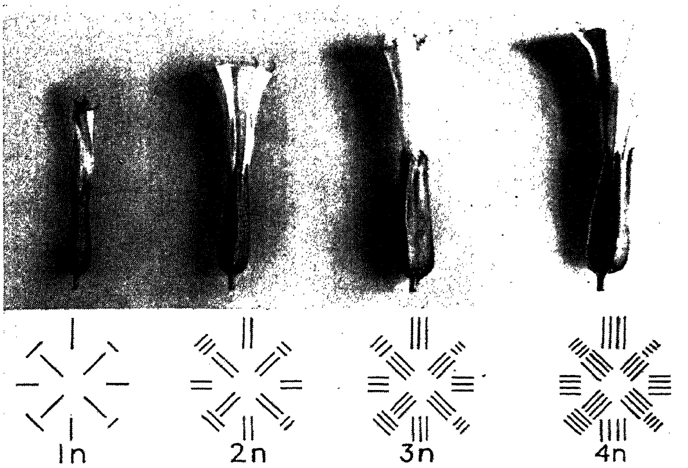


Fig. 53. Four *Datura* Blossoms Ranging from Haploid (left) through Diploid and Triploid Tissues to Tetraploid Flower on Right. In other words, stepwise developments in the production of higher type tissues are represented from left to right. (Courtesy A. F. Blakeslee and A. G. Avery. Reproduced by permission of Journal of Heredity).

range from half-normal (haploid tissue), through diploid and triploid tissues, to twice normal (tetraploid tissue resulting from doubling of chromosomes).

Methods of Applying Colchicine

There are various ways in which colchicine may be applied to plants. In one instance seeds may be soaked in colchicine solution before planting. A weak solution of this alkaloid may be sprayed onto the plant's foliage by means of an atomizer, or even applied from a medicine dropper. Or, a paste of colchicine in lanolin may be rubbed onto the foliage and stems. Seed which have been soaked in colchicine solution and then planted give rise to very odd specimens. Figure 54 shows seedlings of *Cosmos* two weeks after planting. *A-A′* specimens were grown under normal conditions without colchicine treatment. Those represented by *B-B′*, on the other hand, were soaked for four days in 1:2000 solution of colchicine prior to planting. Both *A* and *B* were planted at the same time. The swelling of the stem and almost complete absence of root growth are characteristic after-effects of colchicine treatment.

Figure 55 shows two hybrid tobacco plants, one of which (*B*) was treated with four drops of 0.4 per cent colchicine solution. The characteristic roughening of *B* is clearly evident.

Chromosome Doubling Not Always Desirable

Although colchicine treatment of many species of plants will often lead to larger specimens in the second and succeeding generations, this internal remodeling of plants is not always to be desired or recommended. For example, tetraploid tomatoes are reported to be distinctly inferior in size and taste to the diploid type. Oranges which have undergone chromosomal doubling are likewise said to be of an inferior grade. Nevertheless, the extensive experimentation being carried on at present by the large seed houses throughout the country will no doubt lead to many improved plants, particularly in the realm of floriculture, where plants are not intended as food.

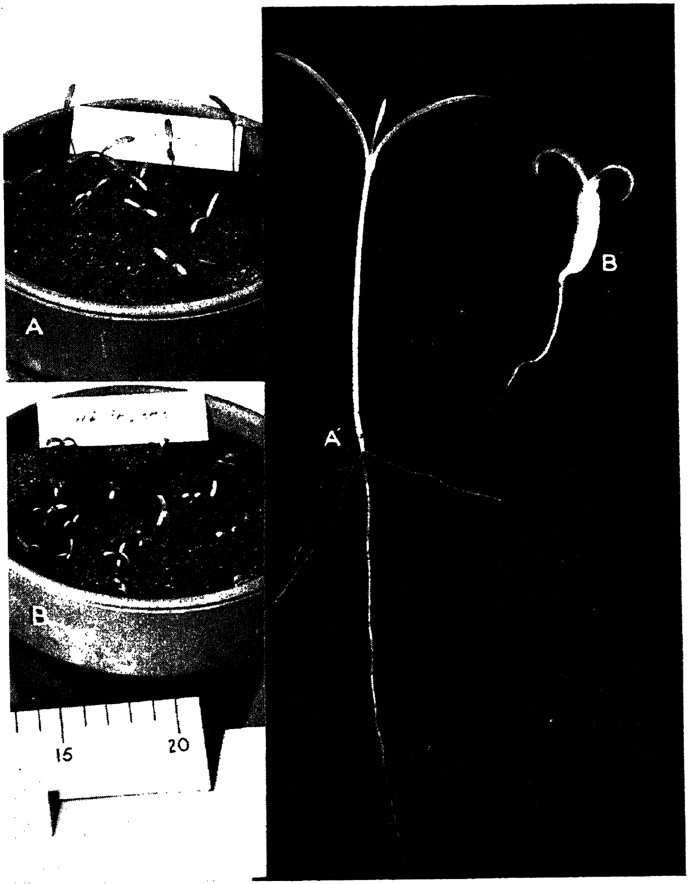


Fig. 54. Seedlings of *Cosmos* Two Weeks after Planting. *A-A'* were grown under normal conditions. *B-B'* seed were soaked in 1:2000 colchicine solution before planting. (Courtesy A. F. Blakeslee and A. G. Avery. Reproduced by permission of Journal of Heredity).

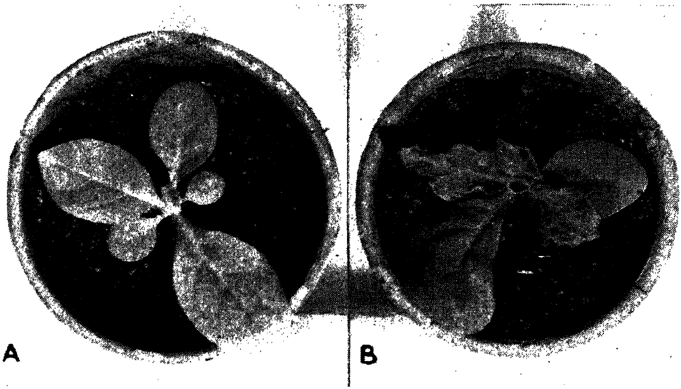


Fig. 55. Characteristic Effects of Colchicine Treatment. Tobacco plant on right was treated with four drops of 0.4 per cent colchicine solution, and its leaves appear to have tetraploid tissue. (Courtesy A. F. Blakeslee and A. G. Avery. Reproduced by permission of Journal of Heredity).

Effect of Hydrocarbons on Plants

Ethylene Gas

It was stated in a preceding chapter that illuminating gas produced a characteristic drooping (epinasty) of the branches of normal plants. There are several hydrocarbon gases (compounds containing carbon and hydrogen) present in illuminating gas that are particularly responsible for this effect. The most potent of these is ethylene gas, possessing the chemical formula C_2H_4. This material, which is used to some extent as an anesthetic, is also employed extensively in the ripening of fruits. It is produced in large quantities as a by-product in the manufacture of gasoline. Its effects on different plants are very interesting, to say the least.

Drooping Caused by Ethylene

In the first instance, ethylene, when diluted with many mil-

lion times its volume of air, produces a characteristic drooping of plants which is remarkably similar to that produced by certain plant hormones (indole compounds). For this reason some experimenters believe that ethylene should be classified as a true plant hormone (see Fig. 57, page 137).

Ethylene Produced by Some Plants

It is interesting to note that even though ethylene is used in ripening some fruits, it is actually manufactured by certain flowers and in some leaves, etc. For example, apples produce enough ethylene to inhibit the sprouting of potato tubers kept within close range.

Another peculiar property of ethylene is its ability to initiate root growth. In some cases these roots may even occur in strange places such as on the upper branches of plants. Acetylene, and even carbon monoxide, resemble ethylene somewhat in this respect. It has also been found that when ethylene and beta-indoleacetic acid, each of which alone is capable of increasing root growth, are used together, the increased root growth far exceeds the additive effects of the two materials separately.

Regulating Dormancy of Plants

Some very interesting work has been carried on by Denny, at the Boyce Thompson Institute for Plant Research, on the effect of certain chemicals on the sprouting of various tubers, etc. Ordinarily tubers, such as the potato, must lie dormant for several months after harvesting before they are capable of being sprouted for another crop. After testing a number of substances Denny found that ethylene chlorohydrin (a chemical containing carbon, hydrogen, oxygen and chlorine) was capable of reducing the dormant period in tubers by several months. New tubers are merely dipped in about a one per cent solution of this chemical, removed and placed in a closed container for twenty-four hours (to allow time for the chemical to act), and then planted. The results are strikingly illustrated

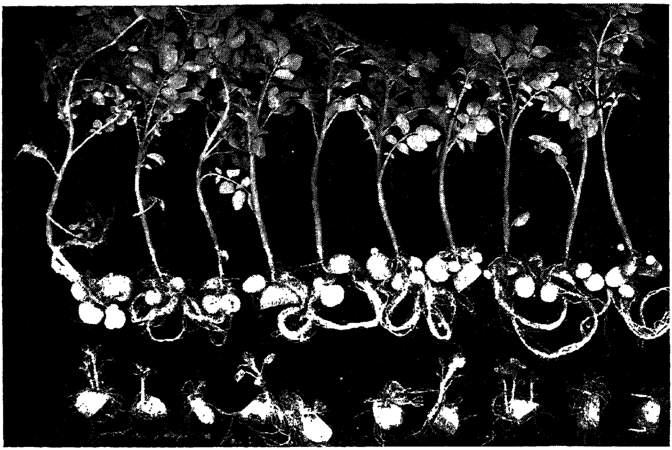


Fig. 56. Effect of Ethylene Chlorohydrin on Dormant Tubers. Sliced tubers in top row were dipped in 1 per cent ethylene chlorohydrin solution before planting. Those in lower row were dipped in water before planting. Both groups were planted at same time. (Photo courtesy F. E. Denny, Boyce Thompson Institute for Plant Research, Inc., Yonkers, N. Y.)

by Figure 56. The two groups of tubers shown here were planted at the same time, the top row receiving the chlorohydrin treatment. Sodium thiocyanate likewise produces early sprouting of dormant tubers. Another phenomenon observed in this work was that thiourea (a compound chemically resembling urea) possesses a marked ability to bring about multiple budding of plants.

Improving Germination Chemically

More recently thiourea has been tested with lettuce seed, whereupon it was found that this substance produced a much higher percentage of germination than afforded by untreated lettuce seed. A batch of seed moistened with a one-half of one

per cent solution of thiourea gave almost complete germination. Untreated seed, under similar conditions, produced germination of only one-fifth the total seed planted.

Effect of Dyes

Under certain conditions some dyes have been found to hasten the growth of plants. This effect is believed to be due to a sensitization of the leaves to light, thereby allowing the latter to be used more efficiently. It is interesting to note that this identical scheme is used extensively in photography. Certain photosensitizing dyes (substances capable of absorbing light of one wave-length and transmitting that of a different wave-length) are often added to photographic film which is not sensitive to a particular wave-band of light, in order to cause this film to become "affected" by this grade of light. This treatment thereby produces films of faster speeds.

As pointed out in an earlier chapter, only certain portions of the light spectrum are effective in materially aiding the growth of plants. Therefore, if a photosensitizing dye is added to a plant, it stands to reason that more of the light striking that plant's foliage is going to become useful.

Heavy Water in Plants

During the past few years many articles, both popular and technical, have appeared describing "heavy water" (chemically known as deuterium oxide). It occurs in ordinary water in extremely minute quantities. It differs from ordinary water (composed of two atoms of hydrogen and one of oxygen) in that ordinary hydrogen has been replaced by its isotope (chemical twin), "heavy hydrogen," which weighs twice as much as its more abundant brother. This new form of water possesses, in some respects, properties markedly different from ordinary water, and the theory has been put forth that it even exerts some influence on the speed with which old age in man approaches. Nevertheless, heavy water has been tested for its effect on plant growth. It was recently reported that the ger-

mination of wheat seeds was considerably delayed by the presence of heavy water. In addition, roots of wheat seedlings grow only about twenty-five per cent as fast when immersed in deuterium oxide as when in ordinary water.

Hormones and the Future

As can be seen from the foregoing discussions, the role of "special chemicals" in plant life is indeed an important one. Practically all the important work in this branch of plant study has come about in just a few years' time. Indeed, at present the plant research field is literally humming with activity. Just what startling disclosures will be made in this field in the ensuing decade would be difficult, yes, impossible to foretell. Experimental work of such a type may eventually revolutionize the concepts of the plant kingdom. Who knows what the flower bed or vegetable garden of the future will resemble?

CHAPTER SEVEN

COMMON DETRIMENTS

THE space allotted to this chapter will not allow a thorough treatment of the Common Plant Detriments in its broad sense. This has been done in countless volumes which are readily available. Much has been written about the aphis, and probably no trouble would be encountered in finding extensive monographs dealing with other insects such as the boll weevil or with parasites such as corn smut. Rather, an attempt will be made to present a concise and simple resume of factors which adversely affect vegetative growth. It is hoped that this chapter will convey a better appreciation of the struggles for existence which most plants encounter, and that the reader will be in a better position to study and combat various plant detriments when and if they appear.

For the sake of space only those detrimental agents believed to be most likely to inflict themselves on soilless-grown plants will be discussed herein.

Soil Diseases

The soil gardener has troubles to contend with both above and below ground. At the present time soil diseases and blights are becoming so very numerous that some plants have drastic "up-hill" grades to surmount. In addition, insect pests, such as the insidious Japanese beetle, are causing an alarming amount of trouble for those portions of plants exposed above soil. Many of these troubles will no doubt be absent wherever soilless-growth methods are involved. Since most soil diseases subsist on, and are spread by, dead organic matter in the soil, nutrient solution tanks and properly attended mineral aggregates would naturally be expected to be substantially free from these ills. Then, too, the grub-stage insects which bore into

the ground would hardly be expected to swim about very long in a tank of nutrient solution, or to remain in a bed of cinders when the nutrient solution floods the system. These very facts will no doubt have much to do with the future possibilities of soilless growth.

Plant detriments can be conveniently divided into two main classes, namely, *chemical* and *parasitic*. The former type will be discussed first.

Chemical Detriments

In this section will be discussed not only the harmful effects of excessive amounts of various chemicals on plant life, but also deficiencies of certain chemical elements.

Boron Deficiency

It was pointed out in Chapter One that boron (about one-half part per million concentration) is essential for thriving plants. On the other hand a larger proportion of boron (1 to 2 parts per million) is often quite injurious. However, if no boron at all is present, some plants (for instance, apple trees) exhibit faulty sexual reproduction. In the last two instances, then, boron is certainly to be classified among plant detriments.

Poor Aeration a Detriment.

As most plant roots require access to a reasonable amount of air, poor aeration is also placed in the category of detriments. (Some plants, however, are capable of living in a completely submerged condition, for example, various aquatic plants.) It is possible to suffocate a plant just as it is to suffocate animals. (Methods of aeration are considered elsewhere in this book.) For example, along river channels are found some of our most fertile soils. Yet, along these same river beds are swampy places in which perhaps nothing grows other than useless swamp grass. Now, this is not because the soil is "poor," but because any plant that starts in such places is soon suffocated because its roots cannot get air. Oftentimes potted plants may seem to

be "sick" simply because they may have been excessively watered.

In this connection some mention should be made of temperature and humidity. Plants in nutrient solution can be frozen or frost-bitten just as those growing in soil. Extremely dry atmospheres are in many cases unfavorable for obtaining healthy plants. However, it is possible that by having access to an abundance of water, plants grown in nutrient solutions would be likely to withstand somewhat drier conditions than the corresponding soil plants.

Chlorosis

This, a form of yellowing of plants, is not uncommon among them and is deserving of consideration at this time. It may be the result of too much shade; but more often, possibly, it arises from a food deficiency. When iron becomes scarce, chlorophyll production drops off, and the general health of the plant is impaired. If allowed to continue, this condition may eventually lead to the loss of some foliage. Iron has quite a tendency to precipitate from solutions; thus, when one is working with nutrient solutions, it must necessarily be added at intervals of every few days. There is much less harm in getting too much than too little iron. Therefore the grower may rely partly on his own judgement in adding this element.

Since nitrogen makes for good foliage, a lack of this food material may produce unhealthy leafy parts. Deficiency of potash as well as of calcium may lead to spotting, yellowing and drying of foliage.

It is wise to prevent material containing limestone from getting into an aggregate system, for example. It will certainly cause precipitation of much of the food elements. Galvanized containers or connections will be likely to lead to zinc poisoning, just as underground water pipes sometimes injure soil-grown plants. Cases are on record in which moisture condensing and dripping from overhead galvanized pipes in greenhouses has led to plant injury.

Root Injury

If observation shows root injury, one might then suspect the presence of fluorine or excessive chlorine, etc. In purchasing commercial-grade chemicals the reader should specify low fluorine contents (less than 1 per cent). Another point about roots is that nature has provided them with the faculties for excreting acids. In the soil these acids serve to break down insoluble material into an assimilable form, but in soilless-growth experiments these acids tend to accumulate. However, they may be kept from constituting a detriment (in nutrient media) if the solutions are discarded periodically.

Of course, coal-tar and pine-tar products must be kept away, as must also any caulking compound containing lead. Most paints, except the blacks, usually contain pigments which, if carried into solution, would certainly damage plants. All oily materials must be avoided, as these would stop up the pores of the root system with a film of oil.

Insecticides

Among chemical detriments attention must be called to the excessive use of certain insecticidal preparations. Many of the lead and arsenic insecticides have a marked tendency to burn foliage as well as to kill insects. Therefore these substances must be applied with due caution.

Toxic Vapors

Most city atmospheres carry appreciable quantities of sulphur dioxide, which, if absorbed too strongly by leaves, may set up an excessively acid condition therein and lead to burned foliage. Illuminating or city gas produces a characteristic drooping or epinasty (see Figure 57) in plants. The vapors of fresh paint or gasoline likewise are capable of at least slight damage.

Parasitic Plant Detriments

Under this heading will be discussed those injurious agents

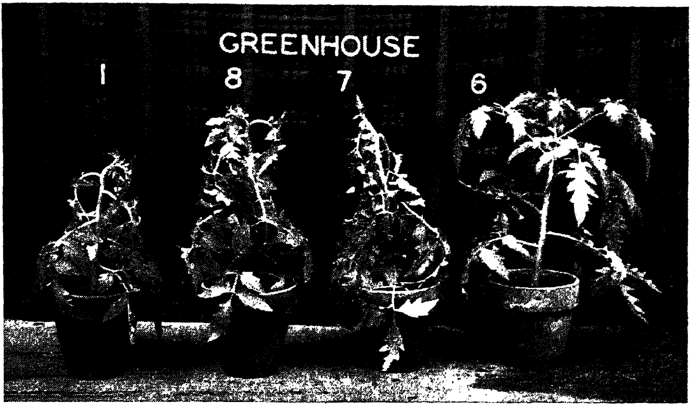


Fig. 57. Effect of Illuminating Gas on Tomato Plants. These remained for twenty-eight hours in various commercial greenhouses in which gas leaks were suspected. No. 1 plant was removed from a house in which Acacias showed almost complete bud and leaf fall. No. 8 and No. 7 plants were in a house in which roses showed leaf fall. No. 6 was in a house not subjected to gas leaks. Healthy tomato plants are often used now in detecting gas leaks. (Photo by courtesy Dr. William Crocker, Boyce Thompson Institute for Plant Research, Yonkers, N. Y.)

represented by the small forms of life, either animal or vegetable, which attack plants and derive their sustenance therefrom. This group comprises the numerous insect pests, blights, rusts, fungi and the like.

Although the soil grower must contend with pests and diseases both above and below the ground, the grower of soilless-growth plants will probably be concerned principally with combating detriments occurring on plant stems and foliage.

Parasitic detriments may be divided into three main classifications, namely, *animal, vegetable* and *bacterial.*

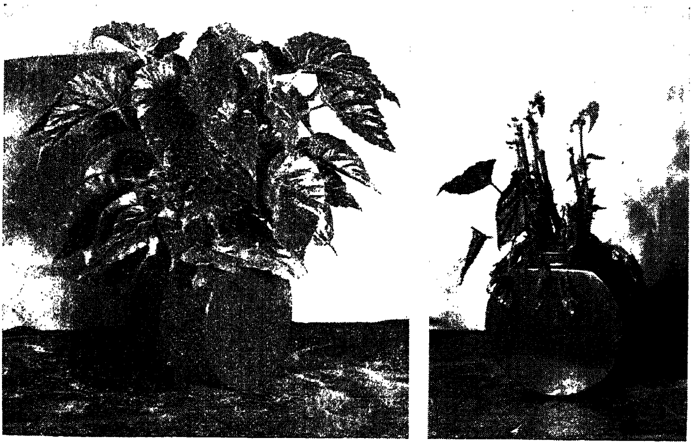


Fig. 58. Large Begonia (left). Photographed on day it was brought into room known to possess slight gas leak. Photo on right shows same plant two days later.

Animal Parasites

This group embraces the vast number of insect pests, small but visible specimens of animal life that attack plants in quest of food. Some of the more common are aphids, red spiders, thrips, coddling moths, white flies, Japanese and other beetles, boll weevils, and countless others of this class.

The most common method for combating insect pests is the use of insecticidal preparations of which an enormous selection is at hand. Some of these are powdery and must be dusted onto foliage. Others are either in solution or in emulsion form and are sprayed onto foliage. Still others are normally gaseous or vaporous and must be used only in confined spaces.

There are two types of insecticidal preparations, namely, *contact* and *stomach poisons.* Some soft-shell insects (for example, aphids and red spiders) may be killed by merely

applying certain chemicals to their skins. The beetle type, or hard-shell, insects must be induced to eat poisonous materials in order to check their development.

Various nicotine preparations and, more recently, substances known as alkyl rhodonates are quite effective as contact materials. On the other hand, paris green (copper-arsenic complex), bordeaux mixture (copper-lime preparation), and the calcium and lead arsenates are noted among stomach poisons. A recent innovation has consisted of combining insecticidal materials with certain plastic substances so that the former would stick both to the insect and the foliage.

One should never have any trouble in procuring a good insecticidal preparation for a particular purpose. A large collection is available. Each manufacturer usually determines the best conditions for his own preparation, and it is advisable to follow these rather closely. Too strong solutions are damaging to foliage, and excessive dilution in order to increase covering power merely results in weakened, ineffective sprays.

Vegetable Parasites

In this group we find the vast number of fungi comprising the smuts, blights, rusts, etc., such as corn and wheat smuts, oat-crown rust, and others. Of the fungi there are three different and distinct types, the classifications depending on the manner in which the respective fungi attack plants. Some of these opposers of plant growth live only on inanimate organic matter (dead tissue). A second class attacks living cells of plants that are physiologically weak, that is, damaged by climatic conditions or bruised, etc. A third group of fungi, and by far the most destructive, comprises those capable of attacking even the healthy plants.

In general the methods of combating fungi are more or less similar to the treatments recommended for insect pests. The fungi differ from insects in one respect, however, in that they may be carried by seeds prior to planting. In a great many cases plant seeds are given sterilization treatments consisting

of subjecting the seeds to poisonous gases, etc., to rid them of this type of organism.

Algae Growth and Prevention

In soilless-growth work care must be taken to protect roots from the light. Otherwise there is a tendency for algae to develop and at least mechanically clog root pores. Almost any sample of water will carry enough fungi causing algae growth to give visible indications of their presence if left exposed to the light for any appreciable time.

The green algae scum often observed clinging to moist flower pots or in shallow ponds during warm seasons may be composed of a number of individual species. Most of these are very easily killed by small traces of copper, and this element may be added to nutrient solutions for this purpose (see Chapter Eight). However, some algae may survive the concentrations of copper tolerated by plants.

In water-culture experiments periodic flushing of tanks is usually sufficient to prevent appreciable trouble from these fungi. In mineral aggregate systems a greenish film may be found forming over the surface of beds of sand or cinders, etc. However, since it does not penetrate below this surface (algae cannot live in the absence of light), the only objectionable feature is that of appearance. All in all, algae should demand no particular attention, as long as solutions are changed regularly.

Bacterial Parasites

Plants, like animals, are subject to diseases in which actual bacteria are concerned. However, plants are affected to a lesser extent than are animals, for the reason that the alkaline conditions in an animal body are usually more favorable to the growth of bacteria than is the acid condition of vegetable cell-fluid. At the same time not all bacteria-plant relationships are to be considered unfavorable. On the contrary, some plants are tremendously benefited by alliances with certain bacteria.

Into this category fall many of the legume crops. Certain bacteria live on the roots of the crops, deriving their food from the latter, but, at the same time, produce nodules on the plants' roots by means of which the bacteria are able to deliver nitrogen to the plant in an available form—nitrogen that these tiny organisms have drawn from the air and changed into a different and usable form.

Common Symptoms in Plants

Obviously a detailed discussion of even a part of the diseases capable of striking plants is beyond the scope of this book. However, it is felt that the reader's awareness that such things exist and his ability to recognize danger should lead to the production of better plants. In view of this a list of a few common symptoms of plant ailments is given below. When any of these appear in your plants, set out immediately to find the cause and to remedy it.

1. *Wilting and drooping.*
2. *Loss* of *color, yellowing.*
3. *Spots and perforations in leaves.*
4. *Malformations* such as galls, tumors, misshapen roots and branches, etc.

Naturally, the best way to combat plant detriments is to produce sturdy, healthy plants. The best way to do this, of course, is to supply proper and sufficient food to them. So long as a plant is not "hungry" it can expend more of its energy in throwing off insects and diseases.

It must be borne in mind that a certain amount of consideration should be shown for a plant's general set-up. After all, plants, too, are "human" and should be handled accordingly. A plant which is mistreated or handled roughly is sure to resent it to the utmost. Do not neglect your plants any more than you yourself would want to be neglected. Be considerate of them, and they will surely respond accordingly.

No doubt the bewildered reader is wondering by this time how a plant could possibly grow in the face of such opposition. This thought is indeed justified; and although plants do not always win, nature has created them sufficiently hardy to resist a reasonable amount of disease and insect attack. At any rate, there is every reason to believe that plants grown in nutrient solution will be subject to fewer diseases than affect soil-grown plants, since those portions of soilless plants exposed to nutrient media should remain fairly sterile.

CHAPTER EIGHT

NUTRIENT FORMULAS

VARIOUS forms of use of nutrient solutions instead of soil for the growing of plants have been considered and described in preceding chapters. Something has also been said of the ways in which these solutions are prepared. In this chapter a number of formulas are listed, together with occasional hints which may be used to advantage in mixing and using plant food chemicals.

With the exception of some of the chemicals of Formula VIII, the plant food salts may be handled without fear. They are harmless chemicals and will not burn the skin if even moderate care is exercised.

It seems probable that drug, hardware and department stores and flower shops will stock soilless-growth chemicals to answer the demands of the amateur experimenter.

The several nutrient mixtures included herein have been advocated by soilless-growth research workers throughout the country and have been shown by them to work well. A number of these have been used by the authors and found to give satisfactory results. Nevertheless, no special claims are being made for any one formula over another. These formulas have merely been listed in random arrangement and do not represent any order of increasing or decreasing efficiencies.

The numerous formulas described herein are the results of experimentation carried on in attempts to determine the proportions and mixtures of salts best suited to growing plants by the various soilless-growth techniques. They are of the proper concentrations for procuring desirable growth in plants. In some instances the concentrations of the fertilizing chemicals (not *trace elements*) may even be doubled without harm, the increased food resulting in a stiffer, harder growth.

For convenience to the reader, the teaspoon measures are given with each formula, but it must be understood that this is only an approximate, not an exact, method of proportioning chemicals. The measures given refer to leveled teaspoonful quantities. In view of the fact that some salts are necessarily heavier than others, the conversion of weight to spoon measure must be made for each salt listed. For example, a spoonful of sodium nitrate weighs considerably more than an equal volume of anhydrous (absolutely dry) calcium chloride. Salts that are well ground allow for more accurate measures (spoon).

In the subsequent discussions, "stock" solution, a solution of such a strength as to be convenient for handling and storing, is to be differentiated from "culture" solution, which is prepared by dilution of the former and which is ready for use with plants.

"Stock" solutions of *trace elements* are prepared as follows:

Stock Solution A

In ½ gallon of water are simultaneously dissolved 3.2 grams* (1 teaspoonful) each of boric acid (H_3BO_3), manganese sulphate ($MnSO_4 \cdot 7H_2O$) and zinc sulphate ($ZnSO_4 \cdot 7H_2O$). To this solution ⅛ teaspoonful of copper sulphate ($CuSO_4 \cdot 5H_2O$) is then added if desired. Stock Solution A may be added to culture solutions (see later) at any time before use.

Stock Solution B

Dissolve 0.8 gram (¼ teaspoonful) of iron (ferric) chloride ($FeCl_3$) or nitrate ($Fe(NO_3)_3$) in 1 pint of water. Ferrous sulphate ($FeSO_4 \cdot 7H_2O$) may be used as a source of iron but has a greater tendency to precipitate from solution before use. Ferric citrate, though it dissolves slowly, remains in solution much better than does the sulphate. As iron has a tendency to precipitate in contact with culture solutions, Stock Solution B

* 15.4 grains = 1 gram
28.3 grams = 1 ounce
453 grams = 1 pound (avoirdupois)
473 cc. (cubic centimeters) water = 473 grams water = 1 pint

should only be added immediately before use with plants.

In using any of the culture solutions described hereinafter, Stock Solution A may be added in the proportion of 10 cc. (2 teaspoonfuls) to each 5 gallons of culture solution if pure chemicals are used, or in the proportion of 5 cc. (1 teaspoonful) to each 5 gallons of culture solution if commercial-grade chemicals are employed in preparing the latter.

Stock Solution B should be added to culture solutions just before actual use in the proportion of 20 cc. (4 teaspoonfuls) of B to each 1 gallon of the culture mixture.

Under certain conditions (bright days) iron may be used up very fast by plants. Therefore, if any signs of iron chlorosis (see Chapter Seven) appear, additional iron should thereupon be added.

FORMULA I.—Fertilizing Salts for Culture Solution.

*Recommended and Used by the N. J. Agricultural Experiment Station.**

	Fertilizing Salt			
Unit of Measure	Monopotassium Phosphate KH_2PO_4	Calcium Nitrate $Ca(NO_3)_2 \cdot 4H_2O$	Magnesium Sulphate $MgSO_4 \cdot 7H_2O$	Ammonium Sulphate $(NH_4)_2SO_4$ (Dry)
Grams per 5 gallons of solution	5.9	20.1	10.7	1.8
Teaspoonfuls per 5 gallons of solution (approximate)	$1\frac{1}{4}$	4	$2\frac{1}{2}$	$\frac{1}{2}$

* Bulletin 636

Each of these chemical salts is dissolved separately in about a pint or quart of water, their solutions mixed, and then diluted with water to 5 gallons. For trace elements, Stock Solutions A and B are added as directed.

The inclusion of ammonium sulphate in Formula I is stated to be beneficial in maintaining the pH value of the solution within a smaller range during the life of the solution.

FORMULA II.—Composition for Culture Solution.
Developed by the N. J. Agricultural Experiment Station.

Unit of Measure	Fertilizing Salt: Monopotassium Phosphate KH_2PO_4	Sodium Nitrate $NaNO_3$	Magnesium Sulphate $MgSO_4 \cdot 7H_2O$	Calcium Chloride $CaCl_2$ (Dry)
Grams per 5 gallons of solution	3.9	6.4	10.3	3.2
Teaspoonfuls per 5 gallons of solution (approximate)	1.	1	$2\frac{1}{2}$	1

Each salt is dissolved separately, then mixed and diluted to 5 gallons. Trace elements are added to Formula II in the same manner as to Formula I.

It will be noticed that Formula II contains two elements (sodium and chlorine) not ordinarily considered as plant foods. Nevertheless, they cause no damage to plants in such low concentrations as present here.

FORMULA III.—Culture Solution for Soilless Growth Prepared from Commercial-Grade Chemicals
N. J. Agricultural Experiment Station.

Unit of Measure	Fertilizing Salt: Superphosphate (Mono-calcium Phosphate)	Sodium Nitrate $NaNO_3$	Magnesium Sulphate $MgSO_4 \cdot 7H_2O$	Potassium Chloride KCl
Grams per 5 gallons of solution	5.8	6.4	10.3	3.9
Teaspoonfuls per 5 gallons of solution (approximate)	2	1	$2\frac{1}{2}$	1

Each salt is dissolved separately in about a pint or quart of water. The solutions are then mixed and diluted to 5 gallons with water. Superphosphate usually carries a small amount of insoluble matter which can be allowed to settle, and the clear solution poured off. To Formula III only half quantities of Stock Solutions A and B (trace elements) are added.

Formulas I, II and III have produced very good results with both vegetables (tomatoes, potatoes, radishes, lettuce, etc.) and flowers (begonia, coleus, gladiolus, tulip, rose, gardenia, carnation, snapdragon, gloxinia, tigridia, tuberous-rooted begonia, calla lily, etc.)

Several formulas (IV, V and VI) have been proposed by the Purdue University Horticulture Department for use in the sub-irrigation method of growing plants. These solutions can be prepared using commercial-grade chemicals.

	Fertilizing Salt				
Unit of Measure	Potassium Sulphate K_2SO_4	Magnesium Sulphate $MgSO_4$	Double Superphosphate $Ca(H_2PO_4)_2$	Potassium Nitrate KNO_3	Ammonium Sulphate $(NH_4)_2SO_4$
		FORMULA IV.*			
Grams per 5 gallons of solution	5.6	7.3	8.6	12.0	4.0
Teaspoonfuls per 5 gallons of solution (approximate)	1	$1\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{1}{2}$	1
		FORMULA V.*			
Grams per 5 gallons of solution		4.9	5.7	16.0	4.9
Teaspoonfuls per 5 gallons of solution (approximate)		$1\frac{1}{4}$	$1\frac{1}{2}$	$3\frac{1}{4}$	$1\frac{1}{4}$
		FORMULA VI.*			
Grams per 5 gallons of solution		2.4	2.8	16.0	10.4
Teaspoonfuls per 5 gallons of solution (approximate)		$\frac{2}{3}$	$\frac{3}{4}$	$3\frac{1}{4}$	3

* Bulletin, "Nutrient Solution Methods of Crop Greenhouse Production," Purdue University, Department of Horticulture.

The Purdue experimenters advocate employment of Formula IV during the cloudy months of winter, Formula V

during the moderately bright seasons, and Formula VI during the very bright days of summer. They suggest also that if growth tends to be a little soft with either of these solutions (IV, V and VI), the concentration of the salts may be increased considerably or even doubled.

Although the immediately preceding three formulas were developed for use with the sub-irrigation technique, they are no doubt applicable to other methods of soilless growth as well. In Formulas IV, V and VI no mention is made of adding trace elements because ordinary commercial-grade chemicals normally carry a certain amount of these elements. If desired, Stock Solutions A and B may be added, but not in full quantities.

The following composition developed by McMurtrey* is reported to be quite satisfactory in soilless-growth work.

CULTURE FORMULA VII.

Unit of Measure	Fertilizing Salt					
	Calcium Nitrate $Ca(NO_3)_2$ (Dry)	Potassium Nitrate KNO_3	Monopotassium Phosphate	Magnesium Nitrate $Mg(NO_3)_2 \cdot 6H_2O$	Magnesium Sulphate $MgSO_4$ (Dry)	Ammonium Chloride NH_4Cl
Grams per 5 gallons of solution	19.5	2.1	5.5	6.1	1.5	1.5
Teaspoonfuls per 5 gallons of solution (approximate)	4	$\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{2}$

To this mixture are then added the customary trace elements as directed earlier in this chapter.

At the Boyce Thompson Institute (Yonkers, N. Y.) the following solution of acids and bases has been developed and employed successfully.

* *U. S. Department of Agriculture Tech. Bull.* 340 (1933).

CULTURE FORMULA VIII.

Unit of Measure	Fertilizing Salt: Nitric Acid Conc. HNO_3	Ammonium Hydroxide Conc. NH_4OH	Sulphuric Acid Conc. H_2SO_4	Phosphoric Acid H_3PO_4 (90%)	Potassium Hydroxide KOH	Calcium Oxide CaO	Magnesium Oxide MgO
Grams per 5 gallons of solution	17.1	5.1	3.7	7.5	2.75	2.7	3.2

To Culture Formula VIII are then added the trace elements as described earlier in this chapter. In tabulating the quantities necessary to prepare this culture solution, the directions involving teaspoon measures have been omitted simply because the handling of the acids with teaspoons is hardly to be recommended. Do not allow concentrated acids to come in contact with clothing, skin or metal containers. In diluting concentrated sulphuric acid always pour acid into water, never the reverse.

The eight nutrient formulas listed above have all been subjected to test by various experimenters and have yielded successful results. The reader will probably find that one or more of these will be adequate for growing most of the ordinary plants. For those who wish to experiment, this problem offers interesting possibilities. The proportions of the chemical salts may be varied and the effects produced on the growth of the plant noted.

As to the matter of purchasing chemicals the following suggestions are made. If the reader is desirous of obtaining only a few grams or a few ounces of chemicals, it is perhaps well to procure these from a drug store. Since chemicals bought over a drug counter are necessarily very costly, one should specify the cheaper grades.

For the reader who desires chemicals in several-pound lots, it is suggested that these be bought direct from chemical manufacturers or dealers. Space will not allow a listing of all such concerns manufacturing chemicals. To list only a few would

not be just. Therefore the reader should refer to a commercial buyers' guide or telephone directory in order to obtain the name and location of a nearby chemical manufacturer or dealer. A pharmacist can often be of assistance in informing of retail chemical establishments, and many large drug stores deal in commercial chemicals; but the highly purified grades of chemicals used by pharmacists for medicinal purposes are unnecessarily expensive for soilless growth. In case the reader experiences appreciable difficulty in procuring chemicals, he is advised to communicate with the authors, who will gladly furnish the necessary information.

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